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AIR FORCE GEOPHYSICS LABORATORY

REPORT ON RESEARCH

For the Period January 1983 - December 1984

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This is the twelfth Report on Research at the Air Force Geophysics Laboratory. It covers a two-year interval. Although written primarily for Air Force and DoD managers of research and development, it is intended to interest an even broader audience. For this audience, the report relates the Laboratory's programs to the larger scientific field of which they are a part. The work of each of the Laboratory's seven divisions is discussed in a separate chapter, followed by a listing of its publications. The report also includes an introductory chapter on AFGL management and logistic activities related to the reporting period.

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Report on Research at AFGL

January 1983-December 1984

SURVEY OF PROGRAMS AND PROGRESS

THE AIR FORCE GEOPHYSICS LABORATORY

AIR FORCE

SYSTEMS COMMAND

HANSCOM AIR FORCE BASE

MASSACHUSETTS

June 1985

Foreword

This report summarizes the recent achievements and progress of ongoing programs at the Air Force Geophysics Laboratory. It is the twelfth in a series initiated by AFGL's predecessor, the Air Force Cambridge Research Laboratories (AFCRL). Written primarily for Air Force and DoD managers of research and development, it shows how AFGL met the needs of Air Force systems and extended the technology base in geophysics during the period from January, 1983, through December, 1984.

JOSEPH D. MORGAN, III
Colonel, USAF
Commander

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I AIR FORCE GEOPHYSICS LABORATORY

The mission of the Air Force Geophysics Laboratory (AFGL), Hanscom AFB, Massachusetts, is to understand the geophysical environment in which Air Force systems operate in order to counteract its detrimental effects on these systems, or to use its special properties to their advantage as, for example, in the over-the-horizon radar system, where radio signals are scattered from the ionosphere.

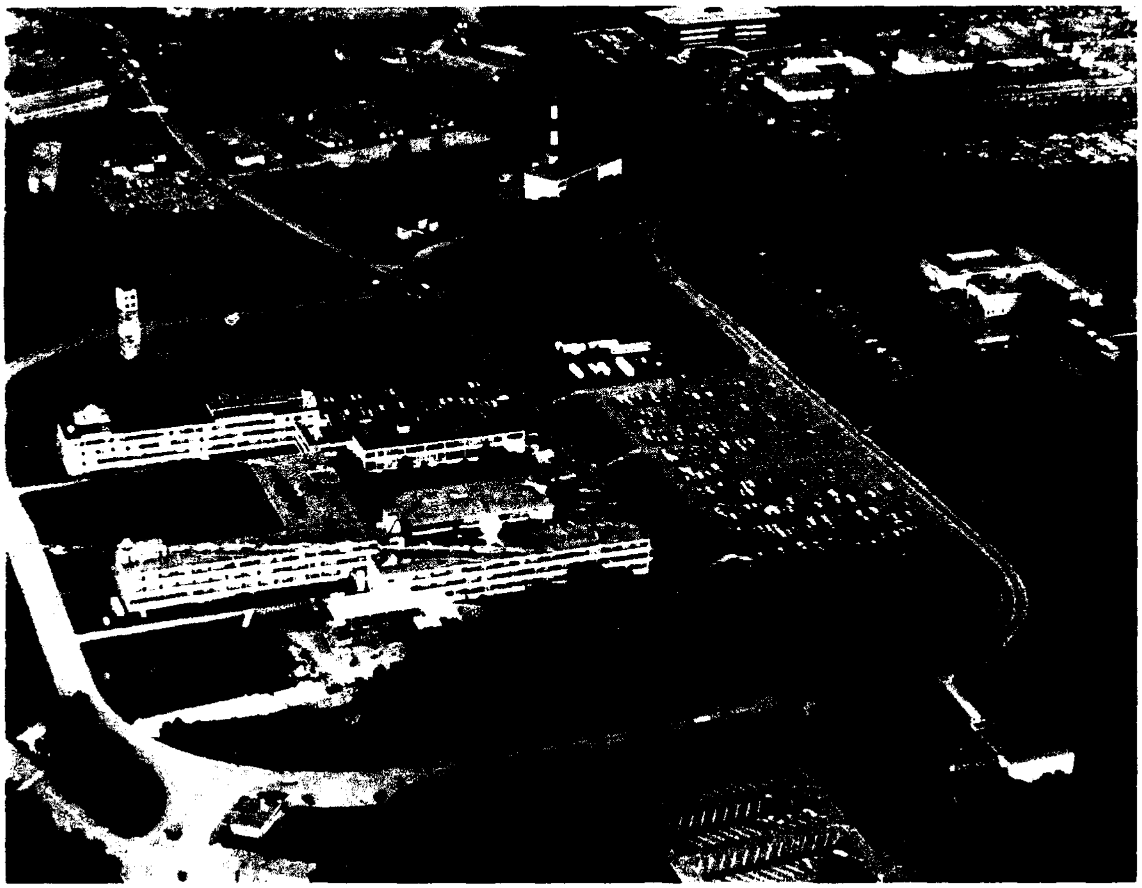
Since 1982, AFGL has been part of the Space Technology Center (STC), with the Air Force Weapons Laboratory and the Rocket Propulsion Laboratory, headquartered at Kirtland AFB, New Mexico. The Space Technology Center reports to the Space Division of the Air Force Systems Command.

This report describes the research programs, activities, and achievements of AFGL from January 1, 1983, through December 31, 1984. During this period, AFGL conducted research, exploratory, and advanced development programs in the physics of space, the ionosphere, the atmosphere, the earth, and optics. The resulting technology was transitioned into the Air Force in the form of computer prediction codes, tactical decision aids, data bases, design standards, atlases, computer models, feasibility studies, and prototype hardware and software.

In 1983, AFGL Commander Colonel John Friel undertook the first major internal reorganization of the Laboratory since the mid-1970's. The Computer Center Branch became the Information Resources

Management Division, recognizing the important role of computers in geophysics research. The Aeronomy Division was abolished, and two new scientific divisions were created: Ionospheric Physics and Infrared Technology. The Terrestrial Sciences Division was renamed the Earth Sciences Division and the Meteorology Division became the Atmospheric Sciences Division. The Laboratory's scientific staff of 283 scientists and engineers was thus organized into seven divisions instead of six: Ionospheric Physics, Aerospace Instrumentation, Space Physics, Atmospheric Sciences, Earth Sciences, Optical Physics, and Infrared Technology. The research programs of these divisions will be discussed in the chapters that follow.

Colonel John Friel commanded AFGL until October, 1983, when he was succeeded by Colonel Gerald P. D'Arcy, who had been Vice Commander of AFGL since 1979. Colonel Rodney Bartholomew assumed the office of Vice Commander in January, 1984. In March, 1984, Colonel Joseph D. Morgan, III, was selected to become the new Commander of the Laboratory. He assumed his duties in June, 1984. In November, 1984, Colonel Morgan established the first System Program Office at AFGL for the management of the CIRRIS 1A program.



The Air Force Geophysics Laboratory is 17 miles west of Boston at Hanscom AFB, where it is a tenant of the Electronic Systems Division of the Air Force Systems Command.

Scientific Staff: The strength of the Laboratory lies in the capability and reputation of its scientific staff. Of the 283 scientists and engineers at AFGL, 98 have doctor's degrees, 79, master's degrees, and 100 hold bachelor's degrees. Several scientists won recognition for their contributions to defense and to science.

Dr. Christopher Jekeli, principal theorist of physical geodesy in the Earth Sciences Division, received the Defense Mapping Agency's Research and Development Award in 1983, the second such award to a member of the Earth Sciences Division in two years. Dr. Jekeli resolved a critical dependency in the calculated accuracy values of the DMA gravity gradiometer, a unique instrument that measures changes in the earth's gravity field from a moving vehicle. Among other applications, it will greatly increase the accuracy of intercontinental ballistic missiles.

Brazil presented the "Merito Santos Dumont" medal to three members of the staff for their contributions to the joint programs that the Laboratory conducted with the Brazilian Institute of Space Activities: Charles D. Howard (1983) and Edward F. McKenna (1984), of the Aerospace Instrumentation Division; and Dr. Rocco S. Narcisi (posthumously, 1984), of the Ionospheric Physics Division.

Two staff members were appointed to the Senior Executive Service: Dr. Donald H. Eckhardt, Director of the Earth Sciences Division, and Rita C. Sagalyn, Director of the Space Physics Division. Dr. George W. Simon, formerly Chief of the Solar Research Branch at Sacramento Peak, New Mexico, was appointed to the super grade of Senior Scientist in the Office of the Director of Space Physics. He is a Payload Specialist Astronaut in training for NASA's Spacelab-2 and Sunlab missions.

The reputation of the Laboratory's scientific staff is further attested by the election of AFGL scientists as fellows of their professional societies: the Optical Society of America (eight fellows), the Royal Astronomical Society, the American Association for the Advancement of Science, the Geological Society of America, and the Mineralogical Society of America, and members of prestigious academies, such as the New York Academy of Science.

A third of AFGL's scientific staff hold the Ph.D. degree.

Other AFGL scientists have been invited to serve on international committees, such as NATO Panel AC243, Panel IV, RSG6 and RSG14; the U.S. National Committee of the International Scientific Radio Union (URSI); U.S. Study Group 6 of the International Radio Consultative Commission; Remote Sensing Group of the International Radiation Commission; International Association of Geomagnetism and Aeronomy (IAGA), Division III, Working Group on Magnetic Pulsations; Joint IAGA/URSI Working Group on Neutral and Ion Chemistry; International Association for Meteorology and Atmospheric Physics (IAMAP) Working Group on Aerosols and Climate; International Agency Coordinating Committee on Middle Atmosphere Programs; the World Data Center A for Solar Terrestrial Physics; International Union of Pure and Applied Physics (IUPAP) representative to the Monitoring Sun Earth Environment Committee (MONSEE) of the Scientific Committee on Solar Terrestrial Physics (SCOSTEP); Solar-Terrestrial Physics Committee, Geophysics Commission of the Pan American Institute of Geography and History; India and U.S. Steering Com-

mittee on Solar Terrestrial Research Collaborative SFC Projects; U.S. National Committee for the International Union of Geodesy and Geophysics, Steering Committee U.S.-Japan Seminar on Heliomagnetosphere; Committee on Space Research (COSPAR), Interplanetary Medium and Its Interactions; Earth's Middle Atmosphere and Lower Ionosphere; Interdisciplinary Scientific Commission on Space Studies of the Upper Atmosphere of the Earth and Planets; URSI/COSPAR Task Group on International Reference Ionosphere, International Standard Organization, U.S. Subcommittee Advisory Group for ISO/TC-20/SC-6, Standard Atmosphere.

Two scientists from the Space Physics Division were invited by the Academia Sinica to give lectures in the Peoples' Republic of China in 1983.

In the United States, AFGL scientists were called to serve on such important committees as the Fletcher Commission (President's Strategic Defense Initiative Committee); the OSD Working Group on

A seminar room is dedicated to the memory of Dr. Rocco S. Narcisi, who died on March 27, 1984. Mrs. Mary Narcisi assists AFGL Commander Col Joseph D. Morgan, III, in hanging a memorial plaque. Dr. Narcisi served as Chief of the Ionospheric Disturbances and Modifications Branch from 1963 to 1984. He was the first to measure the ion structure of the D-region of the ionosphere, including the main meteor belt. He received a USAF Exceptional Civilian Service Award (1972) and the Merito Santos Dumont Award from Brazil (1984), in addition to AFGL's Marcus D. O'Day and Guenter Loeser awards.

Nuclear Disturbed Environments; the IRIS Specialty Group on Targets, Backgrounds, and Discrimination; the Tri-Service Ionospheric Effects Symposium; the U.S. Committee on the Extension to the Standard Atmosphere; NASA/DoD Sixteenth Annual Precise Time and Time Interval Applications Meeting; Military Space Systems Technology Model (MSSTM); Committee on Solar Terrestrial Research and Committee on Geophysical Data of the National Academy of Sciences; Air Force/NASA Spacecraft Contamination Steering Committee and Committee on Spacecraft Environmental Interaction; U.S. National Organizing Committee, 19th International Cosmic Ray Conference (1985); Committee on High Temperature of the American Society for Mass Spectrometry; U.S. Technical Advisory Group to the International Electrotechnical Commission on Classification of Environmental Conditions.

Several AFGL scientists are editors of professional journals and members of publications boards, such as the Chairman of the Books Board of the American Geophysical Union; Associate Editor of the *Journal of Atmospheric Sciences;* co-editor of *Radio Science* (special issues on Ionospheric Studies by means of Beacon Satellites and Ionospheric Effects Symposium 1984); editor of *Proceedings of 1984 MIT Symposium on the Physics of Space Plasmas;* Associate Editor, U.S. National Report to XVIII General Assembly, International Union of Geodesy.

AFGL is well aware that to maintain its excellent technical staff it must interest the best young scientists in its mission and its technical programs. To accomplish this objective, the Laboratory has for a number of years participated in programs to attract and encourage young post doctoral scholars to continue their research at the Laboratory with internationally recognized experts in their fields.

One such program is the National Research Council Post Doctoral Associateship. Through this program, candidates receive one-year appointments (with

an opportunity to renew for one additional year) as regular or senior appointees. Recently, there have been four or five such appointees at AFGL each year, including both United States and foreign citizens.

The AFGL Geophysics Scholars Program was launched in the fall of 1982. This program also awards one-year fellowships which can be reviewed for an additional year. It is open only to citizens of the United States and is designed primarily to attract young scientists with newly awarded doctoral degrees and little or no nonuniversity experience. Geophysics Scholars have numbered eleven to thirteen over the past two years and have come from universities across the country. The contributions of these young men and women scientists, along with the ideas and enthusiasm they bring with them, are readily apparent and stand out as examples of the success of the program.

A third program in which the Laboratory participates is the USAF Summer Faculty Program, administered by the Air Force Office of Scientific Research. It places qualified faculty members from universities across the country in Air Force laboratories during the summer months. AFGL has benefited from twelve to fourteen such appointees each summer during the past two years.

During the reporting period, the Laboratory sponsored a number of key workshops in which teams of scientists from other government agencies, universities, and private contractors joined the AFGL staff to pool information and plan research on such problems as auroral disruptions at high latitudes that degrade radio and radar transmissions (HILAT Workshop, 1983); the physics of the polar cap, in which theory lags behind experimental data (Polar Cap Workshop, 1983); space hazards to astronauts (Space Radiation Environment and Radiobiological Effects Workshop, 1984); and space hazards to modern microelectronics (Space Radiation Effects Science Team of Combined Release and Radiation Effects Satellite, 1984).

AFGL scientists also published in the open literature 385 journal articles and 94 reports and presented 284 papers at scientific meetings. Bibliographies of these items are included at the conclusion of each of the following chapters.

Annual Budgets: The annual budgets for the two years covered in this report are shown in the accompanying table. The totals include salaries, equipment, travel, supplies, computer rental, service contracts, and those funds going into contract research. The largest expenditure is for contract research and development.

Funds received from AFGL's higher headquarters, the AFSC Director of Science and Technology (DL), and to a lesser extent those received from AFSC organizations other than headquarters, are used to conduct continuing programs.

AFGL receives support from the Electronic Systems Division, the host organization at Hanscom AFB, in accounting, personnel, procurement, security, civil engineering, and supply. Holloman AFB, New Mexico, provides services to the AFGL Balloon Detachment. AFGL supports RADC's small laboratories at Hanscom in the areas of the Research Library, laboratory materials needed for the ET mission, the computer, technical photography, mechanical and electrical engineering, laboratory layouts, electronic instrumentation, and woodworking.

AFGL contracts are monitored by scientists who are themselves active, participating researchers, and who plan the research, organize the program, interpret the results, and share the workload of the actual research.

Field Sites: AFGL operates several field sites, the largest of which is the Ground-Based Remote Sensing Facility in Sudbury, Massachusetts. During the reporting period, work was completed on a new dual-frequency Doppler-weather radar system operating at a wavelength of 10 cm. It is being used to develop models for the automated interpretation of features of storms that affect Air Force operations. A separate Weather Test Facility is lo-

TABLE 1
SOURCES OF AFGL FUNDS
FISCAL YEARS 1983 - 84

	FY 83 (In Millions)	FY 84
Air Force Systems Command-DL	60,655	64,064
Air Force Systems Command-Other than DL	11,822	8,296
Air Force	142	649
Defense Nuclear Agency	4,928	4,785
Defense Mapping Agency	5,483	2,801
Army	244	1,617
Navy	69	60
Department of Energy	61	101
National Aeronautics and Space Administration	463	238
Department of Commerce	64	40
Defense Communications Agency	1,758	2,000
Defense Advanced Research Projects Agency	440	414
Department of Transportation	0	130
University Corporation for Atmospheric Research	0	3
University of Maryland	26	74
	$86,155	$85,272

cated at Otis ANGB, Massachusetts.

In New Mexico, AFGL operates a balloon launch site at Holloman AFB and at Sunspot maintains the Solar Research Branch (seven scientists) of the Space Physics Division at the Sacramento Peak Solar Observatory.

At Goose Bay Station, Labrador, AFGL's Goose Bay Ionospheric Laboratory studies subarctic events, including the aurora and polar cap absorption of high-frequency radio waves.

AFGL carries out field tests at a number of military installations, including the Fort Churchill, Canada, rocket range; Fort Wainwright and Eielson AFB, Alaska; Albrooke AFB, Canal Zone; Vandenberg AFB, California; and the White Sands Missile Range, New Mexico. In addition, the Poker Flat Rocket Range, Alaska, and commercial airports are also used.

AFGL launched 47 research balloons during this period from its permanent balloon launch facility at Holloman AFB, New Mexico, as well as from temporary sites at Roswell, New Mexico, Corpus Christi, Texas, Vandenberg AFB, California, and Fort Ethan Allen, Vermont. Thirteen of these flights were tethered balloon missions.

During January and February 1983, a tethered aerostat was successfully flown for several weeks from Fort Ethan Allen, Vermont, to test its capability to remain aloft under severe winter conditions, including icing and winds. The Balloon Branches conducted a test flight and successful mid-air recovery of the BAMM II payload, leading to the development flight of the total BAMM system from Corpus Christi, Texas, on June 1, 1984. Again, a successful C-130 mid-air retrieval was effected.

AFGL balloons carried test and experimental payloads for Space Division, Electronic Systems Division, the Department of Energy, the U.S. Army, U.S. Navy, NASA, the National Center for Atmospheric Research, as well as a number of universities.

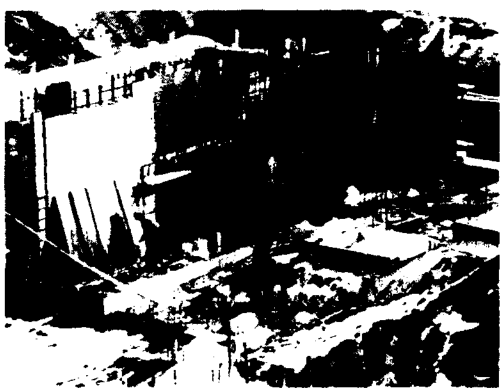
In 1983, twelve sounding rockets were launched in support of AFGL scientists. Ten flights were totally successful, but on

two flights rocket-motor failure occurred (see Appendix B). All payload systems performed as planned.

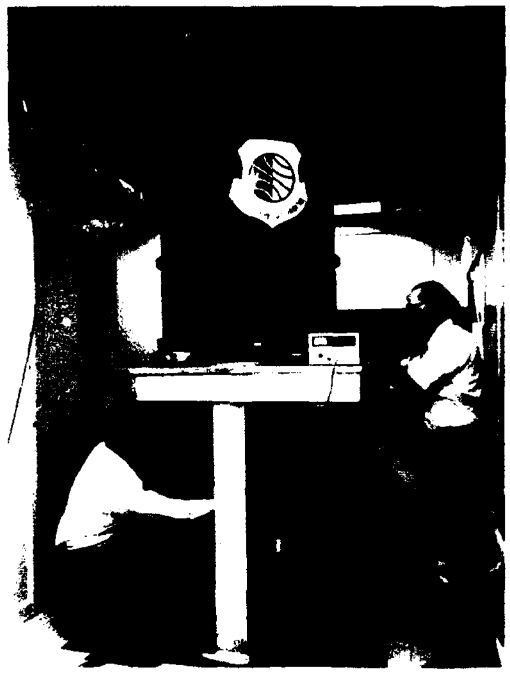
Five sounding rocket programs started development in 1984 and are scheduled to be flown in 1985. About one half of the technical effort normally applied to research vehicle work is now devoted to free-flying satellite and shuttle payload-system integration. In the report time period, experiments were flown on two free-flying satellites and three shuttle flights.

Technology-based research has continued in the areas of microprocessor-based adaptive telemetry systems, intelligent data-processor systems and command/control systems. A base line design of a multiuse shuttle-detached spacecraft system was developed. Utility and cost comparisons show this could be a viable option to the present high-cost shuttle payload system.

In November, 1984, AFGL broke ground for a new two-million dollar Payload Verification and Integration Facility, the first new construction at AFGL since 1970. It will permit AFGL to control the environmental and structural testing of spacecraft, rocket and balloon payloads, formerly done at contractor facilities. Increased reliability of components and payloads is anticipated from the new facility. It will consist of a high bay area and a two-story laboratory area. Environmental test machines for vibration, shock, spin, thermal and structural testing will be installed in the high bay area. A telemetry test facility to monitor environmental tests will be built on the second floor of the laboratory area overlooking the high bay area. A clean room, providing a dust-free environment, will also be constructed in the laboratory. Other laboratories will be equipped for thermal-cycling and thermal-vacuum component acceptance testing.



The foundations of the Payload Verification and Integration Facility are poured in November 1984. Spacecraft, rocket and balloon payloads will undergo environmental and structural testing in this building under the direct supervision of AFGL.

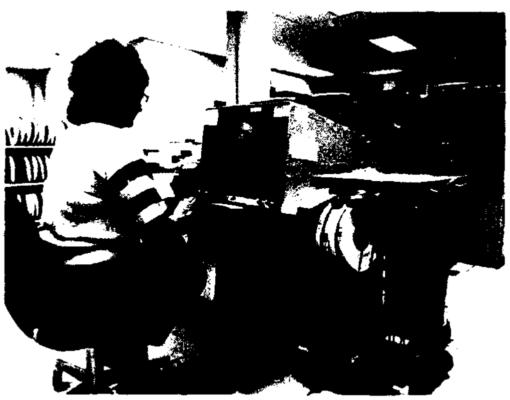


Adjusting the Detector Optics of AFGL's Lidar Receiver in the Receiver Room of the Lidar Laboratory. (The light backscattered from the laser beam is collected by a 36 in. Dall-Kirckham telescope, the bottom of which is shown here.)

LIDAR Sounder Facility: In October, 1983, AFGL's new LIDAR (Light Detection and Ranging) facility became operational. It consists of a laser transmitter, a 36-in. telescope receiver, control electronics, a data processor, and a safety radar.

The transmitter emits ten pulses of light per second with a peak power of 200 million W along a path pointed vertically. The light pulse is 10 ft long. It scatters off aerosol particles, dust, and molecules of gas in the atmosphere. Some of the light energy will dissipate in the air and some will be scattered back to the source, where it will be collected by the telescope receiver. This return signal is then analyzed to obtain the density, temperature, and composition of the atmosphere up to a height of 62 mi. This instrument is being developed for future use at the national space ranges. It will replace the more expensive balloon and rocket technology used in the past to obtain atmospheric information.

AFGL Computer Facilities: During the reporting period, AFGL continued its long-range program to update its computer facilities. The former Computer Center, which consisted of a large, central-site processing facility, has been totally replaced by a broad-band local area network interconnected to a main frame and numerous



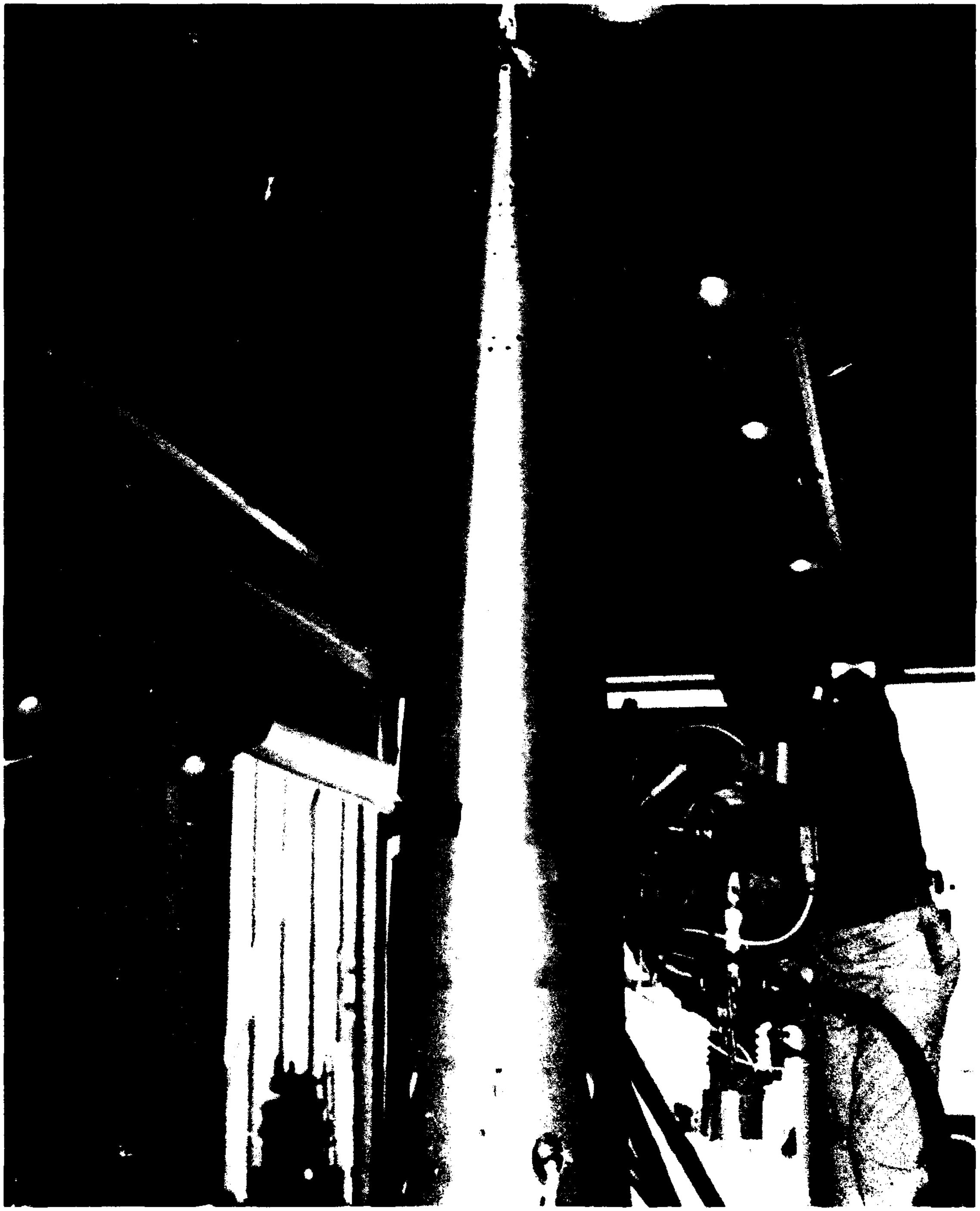
AFGL is replacing its former central-site processing computer facility by a broad-based local area network interconnected to a main frame and numerous medium-size vertical memory hosts. The fully operational network will be implemented by the end of FY86.

medium-size virtual memory hosts. The initial hosts are a CDC Cyber 170-750, a VAX-11/780, and a VAX-11/750. The CDC Cyber 170-750 is to be replaced in July, 1985, with a CDC Cyber 180-860. A pilot network which has been operational since the spring of 1983 consists of three main host systems and numerous intelligent terminals such as IBM PC's, Tektronix color graphic terminals, and an Apple II personal computer, as well as DEC VT100's and VT102 terminals. The fully operational network will be implemented by the end of FY 86 and will be valued at $19 million.

A long-range evolutionary plan was completed during FY 84 for AFGL's migration toward an advanced, full capability, distributed, miltimedia information system. This plan addresses future network enhancements and services, the translation of future user needs into information system capabilities, the time-phasing of information system growth, and the identification and definition of viable alternative information-system architectures to meet the stipulated evolutionary needs.

AFGL Research Library: The AFGL Research Library has the largest and most comprehensive scientific and technical research collection in the United States Air Force. This collection is international in scope and includes extensive holdings in mathematics, chemistry, physics, astrophysics, electronics, and geophysics. Each year the library adds more than 2,500 new titles to the book collection. The library also subscribes to approximately 1800 current periodical titles. Of these, approximately 4,000 volumes are bound each year and added to the permanent collection. In-house and contractor technical reports from AFGL and the Electronic Systems Division are also maintained, both in paper and microfiche.

In addition to its collection of publications, the library offers computer-aided literature searches. This service provides the patron with immediate access to millions of citations from journals, books, reports, proceedings and reviews published throughout the world. On-line interactive searching of the Defense Technical Information Center's (DTIC) several files, as well as many commercially available data bases, gives the library user immediate access to much of the world's scientific and technical information.



Pumping Out Nosecone Section of Aerobee 150-Rocket Before Launching Grazing Incidence Extreme Ultraviolet Spectrometer (40 - 1250 Å).

II IONOSPHERIC PHYSICS DIVISION

Ionospheric physics is the study of the physical and dynamical properties of the earth's upper atmosphere at altitudes from approximately 60 km to 1,000 km, the region where Air Force communications and surveillance systems operate. AFGL measures the electrical structure, electron concentration, total electron content and the ionic structure of the ionosphere, as well as the extreme ultraviolet radiation which creates most of the ionosphere.

The ultraviolet radiations present in the upper atmosphere are the principal energy source affecting the structure and properties of this region. In addition, ultraviolet radiations can be used to help solve defense problems in the areas of missile surveillance and tracking, spacecraft horizon sensing, atmospheric/ionospheric sensing for communication and detection purposes, and technical intelligence. These radiations are measured principally by means of satellites, although rocket measurements are used in the definition of new concepts and in the development of instrumentation for satellite use.

The electrically charged particles in the upper atmosphere also have a significant effect on the propagation of radio waves. The concentration of these particles varies significantly during disturbed conditions such as polar-cap absorption events, auroral events and ionospheric scintillation events and can degrade the performance of satellite communications systems. The Division is measuring these events by means of various instruments on sounding rockets, satellites, the Space Shuttle and the Division's C-135 aircraft.

The atoms, molecules, ions, and photons present in the upper atmosphere constantly interact. These interactions are investigated in the Laboratory, and the rates at which the reactions occur are measured. Theoretical work is conducted on model development of the ionosphere and various plasma effects. The results of these investigations are of direct relevance to the Integrated Operational Nuclear Detection System at Space Division and to the Ballistic Missile Office.

In addition, there is an extensive theoretical and experimental research program to investigate the large-scale processes which structure the global ionosphere (such as the polar cap, the auroral oval, the F-layer trough, and the Appleton Anomaly). The large-scale structuring results from complex interactions of neutral winds and ionospheric plasma, electric field-driven plasma drifts, ion chemistry, and particle precipitation. It affects Air Force systems operating primarily in the hf range.

The Ionospheric Physics Division also investigates the medium- and small-scale processes from tens of kilometers to centimeters in size that lead to the formation of irregularities (as observed, for example, in equatorial electron concentration (N_e) depletions, in the high-latitude ionosphere, and in the recently discovered polar-cap F-layer auroras and patches). The medium- and small-scale irregularities result from various plasma instabilities, on some occasions from localized strong particle precipitation, as. for example, in discrete auroras. They affect radio propagation in the frequency range from hf through shf and are therefore of importance to Air Force systems from the hf-based over-the-horizon backscatter radar to the satellite communications systems (AFSATCOM, MILSATCOM) operating over the whole uhf and part of the shf band. The same physical processes apply to similar effects, even up to ehf frequencies and in the nuclear-disturbed ionosphere.

ULTRAVIOLET RADIATION

UV Imaging from Satellites: Ultraviolet radiation from the earth's ionosphere is being used to develop remote-sensing methods for determining the ionospheric electron-density profile and for the auroral disturbance region. These improved methods will enhance operation of Air Force communications and radar systems. The feasibility of identifying regions at high latitudes that result in radio wave scintillation is also of interest, as these regions simulate the effects of high-altitude nuclear bursts.

As proof of concept of this application of ultraviolet radiation, the Auroral/Ionospheric Mapper (AIM) was launched on the Defense Mapping Agency HILAT satellite in June, 1983. This ultraviolet imager obtained a strip map of the earth's ionosphere seen from the polar-orbiting satellite at about 830 km. A movable mirror on the earth-viewing side of the stabilized satellite made repetitive cross-track observations. When these light-intensity measurements are displayed in proper registration on the ground, a map is produced. The daytime auroral oval can be seen above the dayglow levels. Spatial resolution was about 5 by 20 km; spectral resolution was 30 A ; and any one of a series of preselected wavelengths in the 1100-1900 A region could be used. Excellent images were obtained, but unfortunately an electronics failure after about three weeks of data collection severely limited the amount of data obtained. However, non-imaging photometers at 3914 A and 6300 A continue to give good data.

An improved ultraviolet imager will be flown on the Polar Bear satellite in late 1986. This imager is named Auroral Ionospheric Remote Sensor (AIRS), and it differs from AIM in that simultaneous images can be made in different wavelength bands. During daylight, two UV wavelength bands can be used, such as oxygen 1356 A and a group of nitrogen Lyman-Birge-Hopfield bands. At night,

3914 Å and 6300 Å images can be obtained as well. Also possible will be higher spatial resolution backgrounds for missile defense applications. The simultaneous images will permit tests of remote sensing codes also being developed in this division with the ultimate use to be the Special Sensor Ultraviolet (SSUV) on the Defense Meteorological Satellite Program satellite.

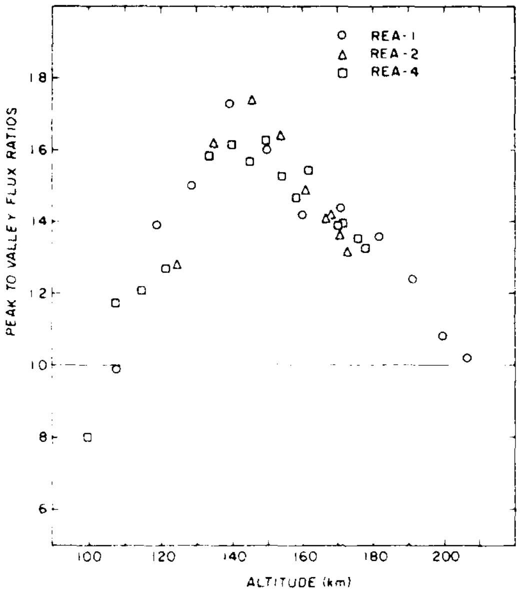
UV Measurements of Missile Engines: As a preliminary step in obtaining ultraviolet measurements of missile exhaust plumes for use in the Strategic Defense Initiative, some measurements were obtained using available laboratory equipment. Static test firings of the Titan II first and second stage engines were conducted at Aerojet General, Sacramento, California, in September, 1984. These observations were limited by the UV transmission of air at ground level to wavelengths longer than about 2000 Å. Total intensity measurements were made and coordinated with imaging data acquired by Science Applications, Inc., on the same tests. Good quality measurements were obtained, and it is planned to continue work of this kind with the goal of building a good spectral and spatial data base on boost-phase missiles.

Solar UV Radiation in Stratosphere: On 20 April 1983, a solar ultraviolet spectrometer was carried to a height of 40 km in the stratosphere by an 11 million cubic foot balloon. Solar radiation in the range from 1850-3200 Å was measured during ascent, a 2 h period at float altitude, and during descent to 28 km, where measurements were terminated. The data gathered were compared with that from similar flights of the same instrument in 1977, 1978, 1980 and 1981. These dates span the rising portion of the current 11-year solar activity cycle, the peak period and the beginning of the decline in activity. Comparison of the measured intensities in the range from 2350-2870 Å shows that the solar cycle change on this wavelength range, which is a large part of the solar heating input to the stratosphere, is less than 7 percent and may be essentially zero.

Data in the range from 2000-2200 Å taken during ascent were analyzed to yield a measurement of the optical absorption coefficient of molecular oxygen. The value of this parameter is important to the photochemistry of the stratosphere as it is a determinant of the concentrations of ozone and atomic oxygen, both highly reactive species. A measurement of the molecular oxygen absorption coefficient is difficult in the laboratory because of the long absorption path required, a measurement condition easily attained in the stratosphere by using the sun as a source.

Structure in 2 to 5 eV Spectra: The existence of marked structure in the 2 to 5 eV energy spectra of near-earth photoelectrons has been predicted by theory and observed experimentally. This structure, arising from resonant vibrational excitation of N_2, is seen as a valleylike dip in the spectra near 2.5 eV and is predicted by theory to be most prominent at low altitudes near 110 km, then to diminish with increasing altitude until it disappears in the 200-250 km region. To investigate this theory, the energy spectrum of low-energy thermosphere photoelectrons was measured by 127° cylindrical electrostatic reflection analyzers on several rocket probes launched from White Sands Missile Range, New Mexico. The electron analyzer was mounted on the back surface of a solar ultraviolet spectrometer that was pointed at the sun by means of a solar pointing control. The electron analyzer faced in the anti-solar direction and, therefore, was sunshaded throughout the data acquisition period. This prevented contamination by locally generated solar photoelectrons.

The rocket data indicated that the structural feature of interest reached a maximum in prominence in the 140 to 150 km region and then diminished at altitudes below 140 km, declining and ultimately disappearing at about 110 km, as shown in the figure. The rocket results, therefore, do not agree with the theoret-

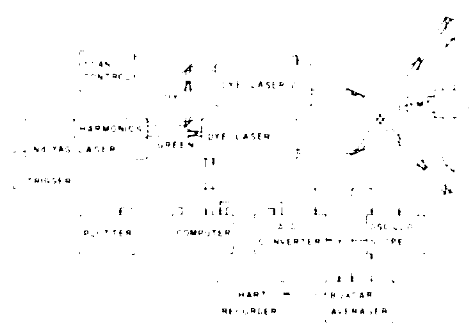


Relative Structural Prominence, as Peak-to-Valley Ratios, Shown as a Function of Altitude for Three Rocket Flight Experiments. (All show as clear maxima in the 140 to 150 km region.)

ical values that predict maximum structure near 110 km. Recently the zero-order theory has been extended to include wave particle interactions. The plasma kinetic approach, which emphasizes collisional processes in predicting the shape and magnitude of these spectra, cannot alone account for the structural profiles. Wave-particle effects must be taken into account in the altitude region below 170 km. A flattening of the electron distribution profile between 2 and 6 eV seems to occur at lower altitudes. This may account for the reduced prominence observed in the rocket flight at lower altitudes in contradiction to theory.

Laser Spectroscopy: Ultraviolet emissions occurring in the upper atmosphere have important remote sensing and surveillance applications. Detailed knowledge must be obtained of the excitation and radiative quenching processes occurring in atmospheric molecules and ions in order to characterize and describe these emissions in complicated environments such as auroras and nuclear-perturbed atmospheres. A laboratory program using lasers is being conducted to determine electronic quenching processes and rates in atmospheric molecules and ions. It is surprising that very little is known about the collisional deactivation of electronically excited molecules. A number of experiments have been conducted to obtain information on the deactivation paths and rates which are important for predicting wavelengths of radiative emissions as well as for laser diagnostics.

A two-laser, optical-optical double resonance (OODR) technique has been used as a direct probe of the electronic energy-transfer process between vibrational levels of the A and X electronic states of N_2^+ (see the figure). For the first time, collisional propensity rules have been obtained for two close-lying vibronic levels of a homonuclear molecule which has no perturbation or "gates" between the states involved. The OODR experiment consists of a "pump" laser which selectively excites a rovibronic level of the A state and a "probe" laser that monitors the collision-induced transfer to the adjacent vibration level of the X state. The electronic transfer rate is comparable to rotational energy transfer. In spite of the competition between these two mechanisms, it is demonstrated that there is a propensity towards ΔJ (angular momentum) ≈ 0 rather than ΔE (energy gap) ≈ 0. Also, the rule which



Schematic Diagram of the OODR Experiment. (Dye lasers one and two produce the pump and probe beams, respectively, of this experiment.)

reflects the permutation symmetry of the molecule is obeyed: s $\rightarrow$ s and a $\rightarrow$ a, where s and a refer to the symmetric and antisymmetric rotational levels, respectively. These are truly electronic energy-transfer processes rather than a form of rotational energy transfer as occurs when the rotational levels are known to be perturbed in the free molecule.

We have also studied the effect of temperature on the electronic transfer rate. The collisional quenching rates of vibronically excited CO^+, which is isoelectronic to N_2^+, have been determined at T = 94 K, 207 K, and 298 K. The rate constants are approximately two to three orders of magnitude larger than recently measured ground-state diatomic ion-vibrational relaxation rates. The effect of temperature for the different vibronic levels is qualitatively the same; the cross sections increase as the temperature is lowered. These results have applications to atmospheric emissions at altitudes where temperatures are much lower than the earth's surface.

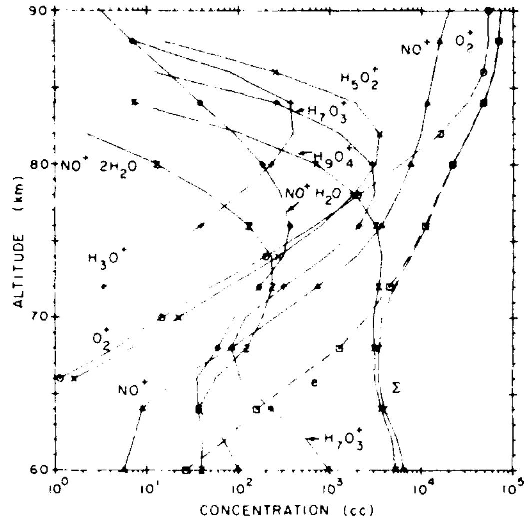
IONOSPHERIC DISTURBANCES

Research conducted on ionospheric disturbances involved experiments using balloons, rockets and the Space Shuttle besides laboratory and theoretical activities. A balloonborne mass spectrometer and a Gerdien condenser were flown out of White Sands, New Mexico, to measure positive ion composition and total concentration. Rockets were launched from Wallops Island, Virginia, to create and investigate artificial ionospheric irregularities. A switched positive/neutral mass spectrometer was flown on the Space Shuttle to determine contaminant gases aboard the Shuttle and for observing equatorial ionospheric irregularities. Various analytical studies were completed involving the disturbed and eclipsed E-region, the quiet and disturbed high-latitude D-region, and the distribution of meteoric metals in the lower ionosphere. Laboratory studies were performed on calcium and samarium. These metals are of interest for release into the ionosphere. Laboratory studies also have been conducted on ionic processes of interest to the ionosphere and to plasmas associated with missile reentry.

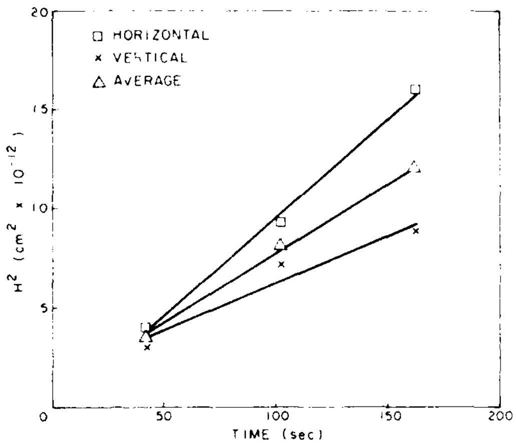
D-Region Studies: No rockets were launched into the D-region during this reporting period. However, several papers on D-region observations were published. Two rockets were launched into a disturbed and eclipsed D-region in February, 1979. The first rocket was launched during totality, and the second rocket was launched into a D-region under 75 percent solar illumination. Ionization below 105 km was created mainly by energetic particle precipitation as exemplified by the increased ion concentrations and the composition signatures of a particle event: a significant enhancement of O_2^+ ions below 105 km and large amounts of $H_5O_2^+$ ions in the D-region which arise out of the subsequent O_2^+ ion clustering scheme. The major ions in the upper D-region were $H_5O_2^+$ ions, while $H_7O_3^+$, $H_9O_4^+$ and $H_5O_2^+$ ions were prominent at lower altitudes. Negative ion distributions from both flights exhibited a distinct shelf at 83 ± 2 km, decreasing by more than an order of magnitude by 90 km, with minima near 75 km. A significant percentage of ions in the 75-90 km range had masses exceeding 160 amu.

A steady-state model of the eclipse was formulated because the electron precipitation was significant and of sufficient duration (see the figure). Good agreement between the data and the model was obtained. This result confirms an earlier finding of a November, 1969, PCA event that the three-body process leading to the clustering of NO^+ ions with CO_2 is the principal loss mechanism for NO^+ ions below 80 km. Carbon dioxide apparently is an important agent in hastening the formation of the heavier oxonium ions, $H_7O_3^+$ and $H_9O_4^+$.

Nitric oxide concentrations of about 3 x 10^8 cm^{-3} for 105-110 km and about 3 x 10^7 cm^{-3} for 90 km were determined. These concentrations appeared to be typical of



Positive Ion Model of the D-region over Red Lake, Canada, during the February 26, 1979, Solar Eclipse. (This model agrees well with the measurements.)



Measured and Average OI (777.4 nm) Glow Halfwidths from SF_6 Release near 350 km. (The diffusion coefficients were calculated to be 1.2×10^{10} cm^2/s vertically and 2.5×10^{10} cm^2/s horizontally, with an average value of 1.8×10^{10} cm^2/s.)

this season (late winter) and latitude (51°N). Analysis of the change in the NO^+/O_2^+ ratio with time during totality led to an estimate of about 50 cm^{-3}s^{-1} for the residual ion-pair production rate at 110 km. Peak ionization occurred near 90 km where the NO^+/O_2^+ ratio was smallest.

Project IMS: The Ionospheric Modification Studies project was a cooperative effort between AFGL and the Brazilian Institute of Space Activities to create and investigate artificial ionospheric irregularities. Other organizations participated in this international effort which was preceded by the successful BIME (Brazilian Ionospheric Modification Experiment) program conducted in Brazil during September, 1982. The IMS program was launched out of Wallops Island, Virginia, during November, 1983. Unfortunately, neither of the two Brazilian rockets, each bearing AFGL mass spectrometers, functioned properly. A third rocket, Nike Tomahawk A08.708-2, successfully injected 20 kg of SF_6 into an O^+ – electron concentration of 3×10^5 cm^{-3} (see the figure).

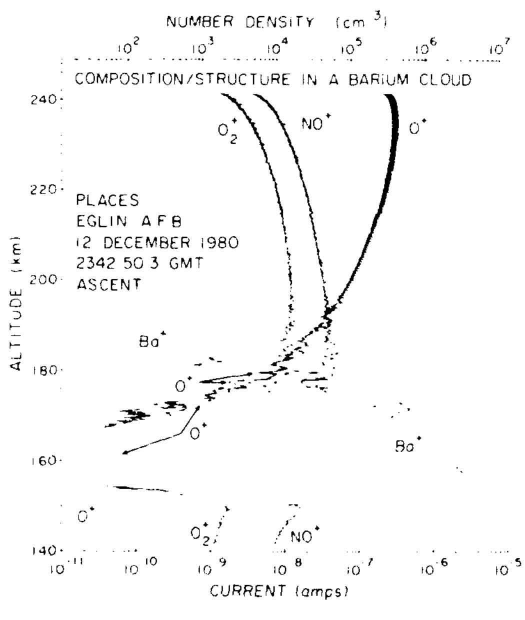
The release resulted in OI 777.4 nm emission intensities exceeding 300 Rayleighs, which lasted a few minutes. (By contrast, the tropical nightglow is about 40 Rayleighs for plasma densities of 3×10^6 cm^{-3}.) Radiative recombination, $O^+ + e$, produces the tropical nightglow. For the release experiment, the process is $SF_5^- + O^+$. A similar process may also excite the 844.6, 135.6 and 130.4 nm permitted lines of atomic oxygen.

Analysis of the intensified video imagery of the 777.4 nm line has provided the first measurements of atmospheric diffusion and wind velocity at high altitude (350 km). The average value of the diffusion coefficient, 1.8×10^{10} cm^2/s, is close to that expected for interdiffusion of atmospheric species at 350 km.

Chemistry of Metals in Ionosphere: Metal atoms are deposited naturally in the ionosphere by meteoric ablation, and they are released intentionally for various ionospheric investigations. Dissociation energies of 3.30, 4.51, 3.07, and 4.57 eV were measured in the laboratory for CaO^+, $CaOH^+$, SrO^+ and $SrOH^+$, respectively. These values led to ionization potentials of 6.9, 5.6, 7.0 and 5.1 eV, respectively, for the neutral species. The cross section for the exothermic reaction $Sm^+ + O_2 \rightarrow O + SmO^+$ has been meas-

ured at 0.2-20 eV. The thermal rate constant is estimated to be about 2×10^{-10} cm^3/s.

Analysis of a barium release over Eglin, AFB, near midnight on December 12, 1980, was completed. Barium ions were found to increase the plasma concentration by a factor of 200. Ion composition measurements provided direct evidence for what could be interpreted as a low-altitude image cloud. Fluctuations in ion concentration above and below the barium cloud were due to the ambient ions NO^+, O_2^+, and O^+. With the exception of an NO^+ dominated region on the topside of the barium cloud, there was a noticeable absence of medium to intermediate structure at wavelengths of 1 to 4 km (see the figure).



Measurements from a Twilight Release of Barium into the Lower Ionosphere.

Mass-spectrometric observations for meteoric species in the upper D-region and lower E-region were compiled. An assessment of the data revealed that Fe and Mg, major meteoric metal species, probably attain peak concentrations of about 10^5 cm^{-3} near 92 km. Ionic concentrations are about two orders of magnitude lower except under auroral ionization conditions, when enhanced levels of NO^+ and O_2^+ increase peak metallic-ion concentrations to 10^4 cm^{-3} by means of charge transfer with Mg and Fe. For quiet conditions, metal ion concentrations may vary diurnally by as much as a factor of 10, the highest ion populations being before sunset and the lowest prior to sunrise.

Progress concerning the chemistry and modeling of atmospheric sodium has been accomplished on contract. The three-body process $Na + O_2 + N_2$ proceeds with a rate coefficient of about 2×10^{-31} cm^6/s and about a $(300/T)$ temperature dependence. The analogous coefficient for potassium was found to be a factor of 3 larger. (The chemistry of Na and K is of interest also to missile plume chemistry and muzzle flash chemistry.) The reaction of NaOH with HCl was found to occur at about the kinetic collision rate. The reaction NaO + HCl, also yielding NaCl, was found to be similarly fast. Modeling efforts lead to Na profiles compatible with the observations within experimental error. The compound NaO_2 is found to be an important reservoir for sodium species in the atmosphere. The role of NaOH as a temporary reservoir for sodium and its possible effect on stratospheric chlorine chemistry remains unclear.

Stratospheric Composition: The trace gas composition of the middle atmosphere has been studied to determine if gaseous emissions from various Air Force operations might contribute to the catalytic destruction of the ozone layer. Whole-air samples were obtained in-situ from a balloon platform in a series of twenty-six flights conducted between 1975 and 1984. Details of the whole-air sampling method and the field program are contained in the 1979–1980 *Report on Research* (pp. 16–17). A summary outline of the fluorocarbon and oxides of nitrogen measurements and conclusions for flights conducted through 1982 are contained in the 1981–82 *Report on Research* (pp. 14–15). For the

1981–82 flights the standard measurements of fluorocarbon content were supplemented by the determination of mixing ratios for all other significant chlorine species. With the exception of acidic and particulate chlorine species, the new species were studied using gas chromatography in a manner similar to that for the fluorocarbon determinations. Acidic and particulate chlorine content were determined using both wet chemistry and neutron activation analysis (under both cooperative and contractual support) of filter samples gathered on the same platform concurrently with the whole-air samples. Compilation of all relevant data was completed during the current reporting period and led to values for total chlorine content that were consistent with model predictions. There have been few such measurements and, more importantly, these are the first to provide not only the total chlorine value but also the relative contributions of all contributing species. These results add considerably to our ability to understand the chlorine cycle and its potential effect on the ozone layer. It confirms our earlier conclusions, based on measurements of stratospheric fluorocarbon content, that Air Force utilization of fluorocarbons has had no adverse effect on the middle atmosphere.

The hydrocarbon content of the middle atmosphere also affects ozone chemistry. The hydrocarbon content can be markedly increased by aircraft emissions in the lower stratosphere. Whole-air samples were obtained from a single balloon flight conducted in 1984 in a cooperative effort with NASA. The samples were analyzed for the content of the several hydrocarbon species present. The data not only added to the sparse data base for some of these species but also provided insight into Air Force aircraft operations in the region where the flight was conducted. The relative changes in the content of certain of these species in the upper troposphere and lower stratosphere can provide information on the in-situ efficiency of the jet aircraft engines.

The expertise developed at AFGL in the application of gas chromatography towards the analysis of whole-air samples from the middle atmosphere led to two other applications of Air Force interest. Position location uncertainty (PLU) is the hallmark of certain potential missile deployment strategies. It is necessary, therefore, that gaseous emissions at trace levels from the site not compromise the PLU. From whole-air samples gathered by AFGL near several existing and potential missile sites, the trace gas content was determined using gas chromatography, and the results proved the feasibility of using gas chromatography for ascertaining PLU integrity.

The second application of gas chromatography was for chemical warfare (CW) agent detection. Most research directed toward achieving CW agent detection and warning concentrates on area detection systems. The Air Force also has expressed a need for a reliable point detector for use in shelters. Using both portable and laboratory gas chromatograph configurations and suitable simulants for the CW agents, we showed that detection and alarming were achievable down to minimum biologically harmful concentrations of the agents and with successful discrimination against interferent gas species. This approach is the only current method capable of being configured to detect known agents as well as unanticipated variants of these agents. Finally, the portable gas unit has been studied for determining the "all clear" condition external to the shelter.

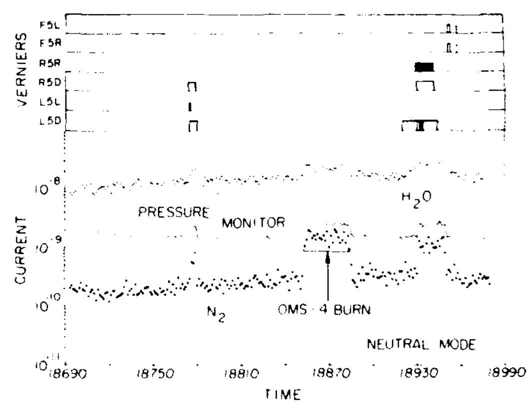
In a separate effort, positive ion measurements also have been made in the stratosphere. A 1982 spring flight gave evidence of positive ions with masses up to 550 amu. A fall flight showed a near absence of ions with masses above 150 amu.

Space Shuttle Mass Spectrometry: The Space Shuttle finished its experimental flights and became a working vehicle toward the end of 1982. In addition to its other tasks, the Shuttle carries scien-

tific instruments into space and serves as the "laboratory" for a large variety of experiments in ionospheric and space physics. One important early experimental program was the investigation of the Shuttle environment. The space around the Shuttle is strongly affected by the presence of the Shuttle and is very different from the natural atmosphere. Evaporation of water from spacecraft surfaces increases the total concentration of neutral gases surrounding the Shuttle during all periods of a short mission. Shuttle operations such as rocket engine firings and water dumps also cause momentary large changes in the pressure and composition of the gas near the Shuttle. The gases released from the Shuttle in orbit cause no damage to the natural atmosphere. However, reactions between the gases in the Shuttle environment and the atmosphere do affect the scientific measurements made from the Shuttle. An understanding of these interactions and of their influence on the scientific measurements is critical if the Shuttle is to be used as a platform for continued experimentation. To address these problems, the Ionospheric Disturbances Branch of the Ionospheric Physics Division developed a versatile quadrupole mass spectrometer that was capable of detecting both the neutral gases and the positive ion surrounding the Shuttle. In addition, the mass spectrometer was able to measure the energy of the species and, thus, the electrical potential of the Shuttle. The energy analysis also permitted separation of the ambient atmospheric species from the Shuttle contaminants. The sampling speed of the instrument was fast enough to observe the effects of transient phenomena such as the firing of rocket engines and the passage of the Shuttle through ionospheric irregularities. The mass spectrometer was flown successfully on the fourth flight of the Space Shuttle in June and July, 1982.

Many important observations of both the ambient ionosphere and the contaminant environment surrounding the Shuttle were made during the flight. Water and helium were found to be the predominant contaminant neutrals. The concentration of water correlated well with the temperature of the Shuttle, suggesting that the primary source of the water is the degassing of Shuttle surfaces. The concentration of the water decreased over the course of the flight, showing that the Shuttle environment gets cleaner toward the end of the flight. The large concentrations of water measured in orbit during the flight of STS-4 may have been the result of heavy rainstorms just prior to launch.

The Reaction Control System vernier rocket engines (the smallest maneuvering engines on the Shuttle) were seen to have large effects. A plot of the thruster firing history (see the figure), the total neutral pressure, and the concentration of N_2 and H_2O as a function of time shows some of these effects. The exhaust from the engines increased the total pressure at the mass spectrometer by as much as a factor of 2 or 3. The major exhaust products were N_2, H_2 and H_2O. The concentrations of these species increased by up to two orders of magnitude above the background levels. The effects of the thruster firings



Rocket Engine Firing Effects. (The top of the figure shows the history of the vernier thruster firings, while the bottom shows the total neutral pressure (pressure monitor), and the concentrations of water and nitrogen gases. Total pressure and the concentrations of both species increase during the thruster firings. The effects of the fourth burn of the Orbital Maneuvering System (OMS) engine on the same parameters are also shown.)

were very short lived. The pressure rose immediately when the thrusters fired, and decreased to background levels within a few seconds after the end of the firing.

Measurements made in the ion mode showed that neutral gas products from the thruster firing reacted with the ambient O^+ to decrease the overall positive ion density. However, ion molecule reactions between the exhaust products increased the amounts of some minor molecular ions such as N_2^+, NO^+ and OH^+.

When the mass spectrometer was in the ram configuration (i.e., looking into the direction of motion of the Shuttle), it was possible to make measurements of the ambient ionospheric plasma. The characteristic signature of ionospheric irregularities, sudden changes in the overall concentration of positive ions that are not correlated with other Shuttle operations, was observed on at least one orbit.

The energy analysis mode of operation showed that both ambient and contaminant ions have broad distributions of energies that are different from what was expected. Collisions between the outgassing neutral molecules and the incoming ambient particles alter the energy distribution of both types of species. An important part of the reduction and analysis of the STS-4 data has been the development of a model of these interactions. The most detailed study has been of the reaction between ambient O^+ and outgassing neutral H_2O to form water ions. The measured quantity of H_2O^+ can be related to the absolute concentration of neutral water near the entrance aperture of the mass spectrometer.

The Space Shuttle mass spectrometry program is providing a basic understanding of the nature of the Space Shuttle environment and of the ways in which the Shuttle interacts and perturbs the natural ionosphere. The program is being expanded to include several additional flights in the coming few years. The information from this program tells how the presence of the Shuttle interferes with the scientific measurements being made within its payload bay. Thus, the program is critical to the design and analysis of future scientific experiments to be flown on large space vehicles such as the Shuttle.

ATMOSPHERIC ION CHEMISTRY

The primary objective of the program in atmospheric ion chemistry is to obtain information of the reactions of ions in the gas phase with neutral molecules, electrons, other ions, and photons. These reactions are important in the stratosphere, mesosphere, and thermosphere, as well as under other conditions in which weak plasmas are generated, such as combustion and missile reentry. Of principal interest to us are the reactions which control ionization densities in the ionosphere under normal and perturbed conditions. The parameters measured in the laboratory experiments include rate coefficients, cross sections, bond dissociation energies, and electron affinities.

Most of our studies are performed using a Selected Ion Flow Tube (SIFT). In the SIFT, reactant ions are generated either by electron bombardment or as the result of ion-neutral reactions. These ions are mass-analyzed, and the desired species is then injected into a fast flowing ($\sim 10^4$ cm s^{-1}) stream of inert carrier gas, usually helium. Further downstream, reactant neutral gas is injected. Ion-neutral reactions may then occur, usually causing depletion of the reactant ions and formation of a product ion species. The ion composition of the gas stream is monitored with a second mass spectrometer at the downstream end of the flow tube. Reaction rate coefficients are determined by measuring the loss of reactant ions as the flow rate of the reactant neutral gas is varied. The temperature range of these studies extends from 85° K to 500° K. Possible reactant neutral species in the SIFT include atomic hydrogen and atomic oxygen, in addition to more stable species.

Although the positive ion chemistry of the atmosphere is quite well understood, the chemistry of negative ions is less so. Of

particular interest are the reactions by which the dominant stratospheric negative cluster ions are formed. These species generally consist of a core ion, such as NO_3^- or HSO_4^-, to which are attached solvent molecules, such as water, nitric acid, sulfuric acid, or hydrochloric acid. We have recently made laboratory measurements of the rate coefficients as a function of temperature for the clustering reactions of a group of dominant stratospheric ions. The ions are $HSO_4^- \cdot pH_2SO_4^- \cdot qHNO_3$ for p = 0 to 3 and q = 0 and 1. Up to three solvent molecules were found to bond strongly to HSO_4^-. This result is consistent with the fact that the stratospheric ion composition shows a maximum in the concentration of $HSO_4^- \cdot 3H_2SO_4$, with only minor amounts of higher order clusters. The temperature dependence of the rate coefficients over the range of temperatures important in the stratosphere can be expressed as T^{-n}, where n is found to be about 3 for clustering of HCl to HSO_4^- and increases with increasing cluster size. The value of n also depends upon the ligand. For example, n is 4.6 for clustering of HCl to HSO_4^-, while n is 6.9 for clustering of HCl to $HSO_4^- \cdot H_2SO_4$.

Rate coefficients for three-body ion-neutral association reactions are expected to be pressure-dependent at low pressures, becoming pressure-independent at high pressures. In the case of NO_3^- clustering to HNO_3, this behavior was in fact observed, but the limiting value at high pressures was found to be only about 10 percent as large as would be expected for a reaction whose rate is limited by the collision frequency. Rate coefficients for the production and loss of cluster ion species can be used in combination with observed stratosphere ion abundances to derive the concentrations of minor neutral species in the stratosphere. Previous derivations of the concentration of HNO_3 using this technique had assumed that the clustering reaction of NO_3^- to HNO_3 proceeded at the collision-limited rate and thus underestimated the HNO_3 concentration. Use of the recent laboratory measurement of the association rate coefficient brings the HNO_3 concentration estimated using this technique into good agreement with other measurements and model calculations. The laboratory data also permit some assignments to be made of the ion species corresponding to particular mass numbers observed in mass spectrometric sampling of the stratospheric ions. For example, our present laboratory studies indicate that the ions at masses 133 and 231 in the stratosphere are most probably $HSO_4^- \cdot mH_2SO_4 \cdot HCl$ with m = 0 and 1, respectively.

Experiments in which chemicals are released in the ionosphere to create perturbations of the local concentration of charged particles have been performed for about 30 years. Chemicals which attach electrons are used when it is desired to create a region of depleted electron density. Sulfur hexafluoride is such a chemical, forming SF_6^- and SF_5^- when released high in the ionosphere. The presence of these species has been observed by mass spectrometric sampling of the perturbed region. Their presence is expected, since the attachment of thermal electrons to SF_6^- is known from laboratory experiments to produce these ions. Also observed in the perturbed ionosphere is F^-, which is not observed in the laboratory when only thermal electrons are present. Recent studies of the reactions of SF_6^- and SF_5^- with atomic oxygen and atomic hydrogen in the SIFT have provided an explanation. A slow reaction between SF_5^- and atomic oxygen has been observed, producing F^- and SF_4O. Knowledge of this chemistry will permit more accurate modeling and analysis of these chemical release experiments and may also provide another means to measure atomic oxygen concentrations.

Laboratory studies of the reactions of other electron-attaching molecules useful for such ionospheric perturbation experiments have included several species generating PO_3^-. The energy required to detach an electron from PO_3^- is very high, about 5 eV. No ion-neutral reactions destroying this species are known. Cluster-

ing of PO_3^- does occur, but the clustered species has an even higher electron detachment energy than does PO_3^-. The conclusion is that release in the ionosphere of a chemical generating PO_3^- by attachment at thermal energy would provide a particularly effective and long-lasting perturbation of the local ionospheric electron density. Studies of such materials are in progress.

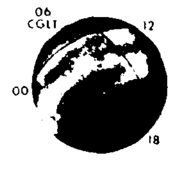
IONOSPHERIC EFFECTS

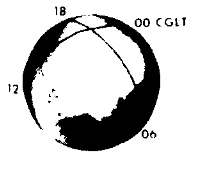
Large-scale ionospheric processes such as the polar cap, the auroral oval, the F-layer trough, and the Appleton Anomaly structure the global ionosphere. This large-scale structuring results from the complex interactions of neutral winds and ionospheric plasma, electric-field-driven plasma drifts, ion chemistry, and particle precipitation. It affects primarily Air Force systems operating in the hf range. Medium and small-scale processes lead to the formation of irregularities from tens of kilometers to centimeters in size, as observed, for example, in equatorial electron concentration (N_e) depletions, in the high-latitude ionosphere, and in the recently discovered polar-cap F-layer auroras and patches. These medium and small-scale irregularities result from various plasma instabilities and on some occasions from localized strong particle precipitation as, for example, in discrete auroras. They affect radio propagation in the frequency range from hf through shf and are therefore of importance to Air Force systems from the hf-based Over-the-Horizon-B (OTH-B) Radar to the satellite communications systems (AFSATCOM, MILSATCOM) operating over the whole uhf and part of the shf band. The same physical processes are believed to drive similar effects through ehf frequencies in the nuclear-disturbed ionosphere.

Theoretical efforts during this reporting period have been concerned with ionospheric irregularity generation, the theoretical basis for satellite-borne optical mapping of airglow and auroral emissions for mapping the global ionosphere, and the modeling of large-scale ionospheric dynamics.

Experimental efforts in the reporting period focused on: determining the nature of the polar ionosphere by using a multiplicity of airborne, ground-based, and satellite diagnostics; detailed mapping of the polar, auroral and subauroral ionosphere by AFGL's Airborne Ionospheric Observatory (AIO), a modified NKC-135 aircraft, in support of OTH-B testing; the continued investigation of equatorial F-layer irregularities, their generation, dynamics and decay; and experiments to artificially disturb the ionosphere, either chemically or by ionospheric heating.

Polar Cap Plasma Characteristics: Of special significance to Air Force systems was a study which investigated the structure and dynamic processes in the polar cap ionosphere with emphasis on determining the source region of polar cap plasma, and irregularity generation and transport. Also, it assessed the severity of outages in Command, Control, and Communication (C^3) systems due to polar-cap ionospheric irregularities. The AFGL Airborne Ionospheric Observatory (AIO) is flown to specific magnetic latitude/local time locations to perform radio wave and optical sensing of ionospheric parameters. These measurements are coordinated with observations using the Sondrestromfjord Incoherent Scatter Radar and the HILAT, DMSP, AFSATCOM and GPS satellites. Extended periods of ground-based observations by the AIO instrumentation provide a supporting multidiscipline data base. The unified description of polar cap F-layer structure previously discovered using the AFGL AIO has been further confirmed and refined. Convecting F-layer ionization patches dominate the polar cap during magnetically disturbed periods, while F-layer auroras occur during quiet periods (see the figure). It had previously been shown that the F-layer auroras are produced by soft (~100 eV) precipitating electron fluxes. New results indicate that the source of the patches is solar-produced





6300 Å All Sky Images of Dominant Features of Dark Polar Cap F-region. (At left, particle produced F-layer arcs. At right, ionization patch. The diameter of the field of view is 1200 km for a 250 km nominal emission height. Shown are the noon/midnight and dawn/dusk magnetic meridians and their intersection, the CG (corrected geomagnetic) pole.)

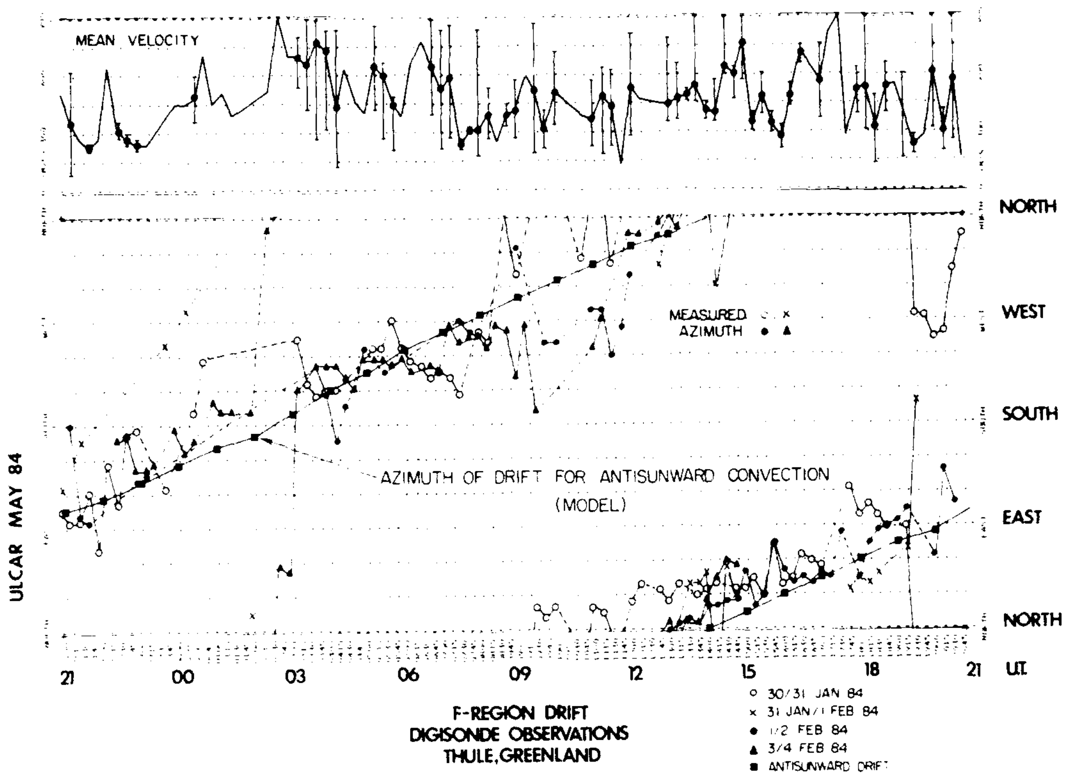
plasma which originates equatorward of the dayside cusp in the sunlit ionosphere. Large universal time variations in patch peak density within the central polar cap are a direct result of longitudinal variations of the maximum plasma density within the source region. The diurnal, seasonal and solar cycle variations of the maximum plasma density within the source region are largely responsible for the observed variations in uhf scintillations. This information will allow realistic modeling of the occurrence and severity of C^3 outages due to the maximum electron densities and the generation of irregularities within these patches.

Coordinated observations were directed at defining the properties of F-region ionization patches in the polar cap and some of the associated implications. Ground-based all-sky images and digital ionosonde measurements were taken at Thule, Greenland, to measure ionospheric structure and dynamics in the nighttime polar cap F-layer. A spaced receiver antenna array used during ground operations of the AFGL aircraft at Thule permitted the measurement of the plasma convection in the central polar cap using a technique developed by AFGL and the University of Lowell. Measurements made during four days of continuous ground operation in early 1984 showed a systematic antisunward convection, i.e., the drift vector rotated through 360° within 24 h (see the figure) in agreement with convection models derived from satellite and ion motion measurements. Measurements in December, 1984, confirmed the usefulness of this technique, and systematic measurements of the convection will begin in 1985 at Qanaq, Greenland, supported by the Danish Meteorological Institute. A comprehensive campaign was begun to measure ionospheric structure and dynamics of nighttime polar cap F-region arcs, more specifically, line-of-sight velocity shears, measured by the Sondrestromfjord Incoherent Scatter Radar, co-located one-to-one with sun-aligned F-region arcs seen on the AFGL aircraft All Sky Image Intensified Photometer (ASIP) in the quiet polar cap. Strong anti-sunward plasma flow ($\sim$1000 m sec^{-1}) measured on one side of the arcs was found to stagnate or reverse on the other side. This is the first experimental verification that these sun-aligned F-region arcs are boundaries between regions of differing polar plasma flow in the quiet polar cap.

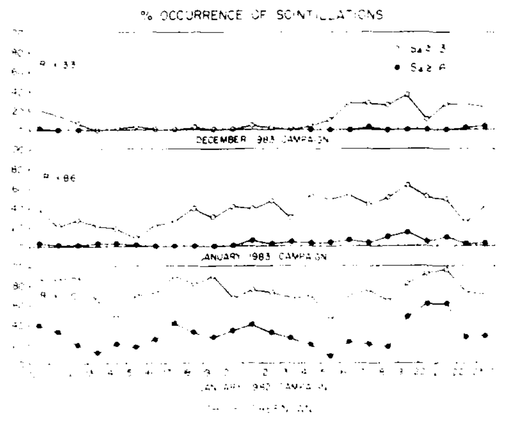
F-region arcs can involve sufficiently high electron concentrations and velocities to be of concern to polar thermospheric temperature, composition and circulation structure due to ion-neutral collisional drag. Ion-temperature enhancements seen near an arc as it slowly drifted transverse to its length are compatible with this effect.

The ASIP data are found to provide an important frame of reference for future polar cap research. The quiet polar-cap sun-aligned F-region arcs identify polar plasma-flow boundaries. They help correct or recognize when vector velocities derived from monostatic Incoherent Scatter Radar (ISR) data, as at the Sondrestromfjord ISR, are subject to error due to rapid variation in time and space. Thus, ASIP data offer a valuable context within which to evaluate nighttime polar ISR plasma velocity data.

Polar Cap Scintillation: An investigation of the polar cap ionosphere near the peak of the last solar cycle identified polar cap F-layer arcs and ionization patches as sources of severe scintillations observed



F-region Plasma Drift Measurement Made in Early 1984 at Thule AB, Greenland, using Digisonde Doppler Drift Technique. (The continuous line connecting the black squares in the UT azimuth graph indicates modeled anti-sunward flow direction. Azimuth is in the CG system.)



Solar Cycle and Diurnal Dependence of 250 MHz Scintillations in the Polar Cap (R = International sunspot number; S_4 = Measure of scintillation intensity ranging from 0 to 1.)

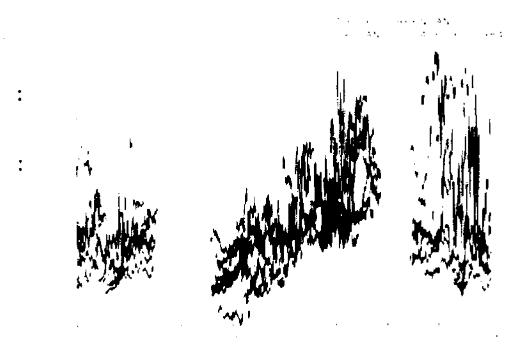
on 250 MHz satellite beacon signals. The continuing investigations in January and December, 1983, and January, 1984, have shown that arcs and patches persist as the dominant features of the winter polar-cap ionosphere during periods of low sunspot numbers. A strong positive solar-cycle dependence of the scintillations was measured during three extended campaigns and confirms earlier measurements, as shown in the figure. The diurnal variation of scintillations is almost flat at solar maximum and has a local time variation very similar to that of the patch-type ionization at solar minimum. Both arcs and patches contribute to substantial scintillations around solar maximum, while only the patches are responsible for the considerably weaker scintillations during solar minimum.

Multipath Effects on Absolute Ionospheric Time Delay: Signals from the Global Positioning System (GPS) satel-

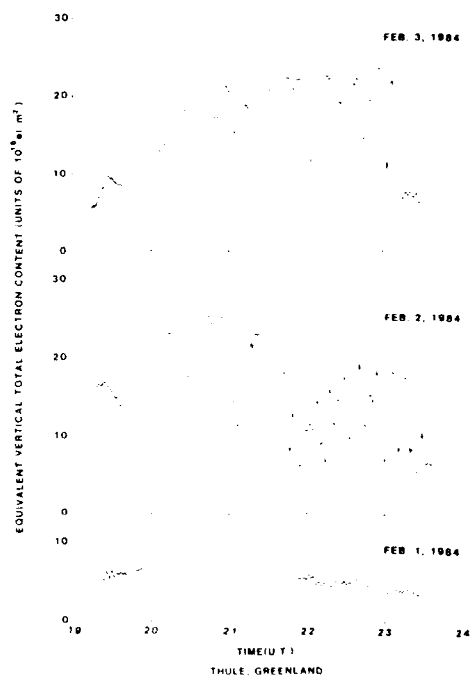
lites can be used to measure absolute ionospheric group delay and relative phase advance. These ionospheric parameters have wide application in providing corrections for military systems requiring knowledge of ionospheric time delay and phase scintillation, such as satellite detection radars. Multipath effects from the local environment of the receiving antenna can cause severe contamination of ionospheric group-delay measurements made with GPS pseudo random-noise (PRN) receivers. Variations in the multipath effects in some typical clean and reflective environments were measured and shown to be consistent with signal analysis for PRN receivers. Since antennas must frequently be located in environments that are much less than ideal, data analysis procedures were developed for minimizing the impact of multipath on the group delay measurement. These include low-pass filtering, day-to-day correlation, and calibration of relative differential carrier phase advance measurements, using subsets of the absolute ionospheric group delay data.

Total Electron Content, L-Band Amplitude, Phase Scintillation: The first absolute measurements of Total Electron Content (TEC) and L-band amplitude and phase scintillations were made from Thule, Greenland, a polar cap station, in early 1984 (see the figure). These measurements were made using signals transmitted from the Global Positioning System (GPS) satellites. The variability of the TEC, especially during the afternoon to pre-midnight hours, is large, with increases in TEC above the background values of greater than 100 percent not uncommon, as may be seen in the figure (LT = UT – 4h). During one disturbed time, quasi-periodic TEC enhancements having periods as short as 10 min and amplitudes equal to the background TEC were observed for over 2 h. The TEC during some of the disturbed periods in the dark Thule ionosphere exceeded mid-latitude daytime values.

Amplitude scintillations were observed, especially associated with the times of TEC enhancements, with some evidence for stronger scintillation occurring during the negative gradients of the TEC enhancements. Phase scintillations were highest during some of the times of en-



Diurnal Behavior of Equivalent Vertical TEC versus UT for the Period January 28 to February 4, 1984.



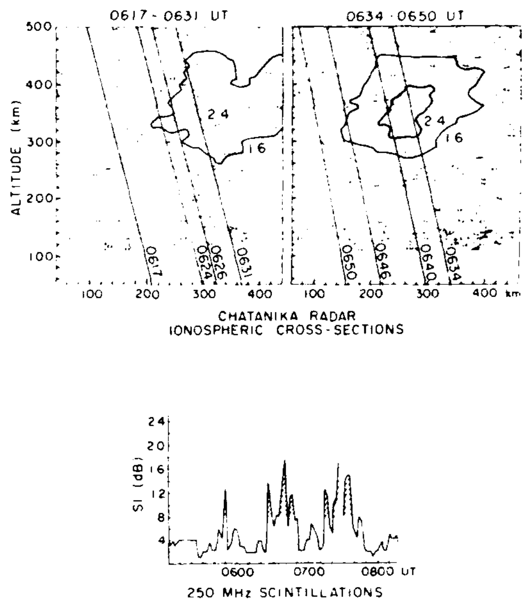
Total Electron Content for the Pre-midnight Hours of February 1-3, 1984.

hanced TEC, and depend critically upon the phase detrend interval used.

Initial results from December, 1984, measurements show TEC variability similar to that of the January, 1984, campaign but of lesser magnitude, possibly a sign of solar cycle control. Further measurements are now being made on a continuous basis.

Coordinated Measurements of Nightside Auroral Zone: The AFGL Airborne Ionospheric Observatory (AIO) performed radio, optical and scintillation measurements on a series of North-South flight legs along the Chatanika radar magnetic meridian. The incoherent scatter radar was operated in a North-South magnetic meridian scan mode to measure ionospheric parameters (electron density, temperature, and ion drift) from 600 km north to 600 km south of the radar and from an altitude of ~ 80 to 700 km. Ionospheric structure measured by the radar was compared with optical and ionosonde measurements from the AIO and with precipitating electron characteristics measured by the DMSP satellite. Long-lived F-region plasma enhancements (plasma blobs) were observed during this experiment. From the simultaneous measurements it is shown that these enhancements were not locally produced by precipitating particle fluxes. F-region electron concentrations, calculated from simultaneously observed precipitating electron fluxes, are significantly less than those observed in the plasma enhancements. These premidnight features (plasma blobs) were in fact observed to be convecting sunward (to the west) at a few hundred meters per sec^{-1}, and were thus presumed to have been produced well upstream in the convection flow, within a region of significantly greater production rate. Intense scintillation of satellite signals due to ionospheric irregularities is generally confined to these regions of enhanced F-region density (see the figure).

Simultaneous measurements of independent parameters identifying the auroral E layer (1–20 keV precipitating electrons, 4278Å N_2^+ emission, foE and the



Oval Boundary Plasma Blobs Observed by the Chatanika Radar. (An aircraft moved under a satellite raypath through the boundary blob—8 representative positions shown—to determine the location of scintillation-causing irregularities. Data show clearly onset of scintillations with crossing of 1.6×10^5 el cm^{-3} contour.)

radar electron densities) all agree well as to location and the latitude profile of the auroral E-layer and associated diffuse aurora.

Auroral E-Layer: An array of ionospheric sounders situated in both east and west hemispheres at high northern latitudes measures the auroral E-layer critical frequency, foEa, simultaneously at 15 min intervals at all locations. In agreement with earlier studies using a similar array of sounders but limited to the western hemisphere, the auroral E-layer is found to have the following property: foEa, hence the precipitated particle energy flux in the continuous or diffuse aurora, is constant in magnetic local time along contours which are parallels of latitude in an offset pole coordinate system - that is, a coordinate system within the CG latitude/CG local time reference frame but with a pole which is offset from the CG pole by several degrees in the anti-sunward direc-

tion. This property is instantaneous so that changes in intensity, location and width occur synchronously throughout a longitudinal extent which is observed to be as great as 270° CG longitude. The latitudinal distribution within the offset pole coordinate system, which is thus instantaneously the same at all observed CG locations, is Gaussian and varies with UT in latitude and intensity. However, the Gaussian scale parameter is found to be constant at 3.2° FWHM (Full Width at Half Maximum) in energy flux (6.4° FWHM in foEa), in all cases where it can be independently determined. Where it cannot be determined, this same value is assumed, an assumption which makes possible in most cases the determination of the location of the offset poles. The present study finds the location of the pole to vary (a condition not observed in the earlier more limited study) within extremes of 86° to 90° CG latitude and 21 h to 03 h CGLT. The Gaussian maximum energy flux varies from 0.1 to 10 ergs/cm^2 sec and the latitude of the maximum, from 68° to 73° offset pole latitude. The temporal variations of these four parameters describe in quantitative terms the dynamics of the entire distribution of energy flux. These parameters have been determined continuously for two periods of 12 h duration at 15 min intervals. With these results it is possible to model the time dependence of the global inputs of power and current into the ionosphere as well as the conductivities produced by this auroral precipitation. Moreover, this work presents the basis for determining a dynamic system of auroral coordinates which is defined by the auroral phenomenon itself.

Global Ionospheric Scintillation: With the launch of the HILAT polar-orbiting satellite, the recording of scintillation data in the polar cap and auroral regions has received greater emphasis. A station has been established at Tromsø, Norway, to receive not only the HILAT beacon but also the quasi-stationary polar uhf radio beacon that is simultaneously recorded at Thule and Sondrestromfjord, Greenland. These stations record the phase and amplitude scintillation of the radio beacon caused by fluctuations in the integrated electron density due to irregularities along the line of sight to the satellite. Scintillation of satellite radio transmissions provides a measure of the severity of ionospheric irregularities over scale sizes of about 10 km to tens of meters for phase scintillations and of 1 km to tens of meters for amplitude scintillations. The first long-term measurements of phase scintillations at high latitude from a quasi-stationary satellite at 250 MHz were reported. Data from December, 1979, through April, 1982, were obtained for Goose Bay, Labrador, and Thule, Greenland. Scintillation magnitudes were higher during the vernal equinox at both stations than during the winter solstice. Goose Bay data showed a well-ordered diurnal variation with a nighttime maximum and daytime minimum; Thule data showed no such ordering. Minimum scintillations were observed in local summer at Thule, while a broad maximum stretches from equinox to equinox through the winter, as may be seen in the figure. A gradual decay in overall scintillation activity with sunspot number is observed. Studies are continuing, with particular emphasis on separating the effects of solar radiation from particle precipitation in the polar cap.

Recording of equatorial scintillations has also continued at Ascension Island. The severity and occurrence of scintillation there have decreased with the decline in the solar cycle.

Evolution of Equatorial Plasma Depletions: The formation of depleted regions within the post-sunset, low-latitude ionosphere has been the subject of a number of observational and theoretical studies. One of the manifestations of these depleted magnetic flux tubes or "bubbles" is a reduction in 6300 A airglow intensity as compared with surrounding regions. These airglow depletions delineate regions of reduced electron density, which constitute the bubble. The use of all-sky

Four-year Survey of Thule 250 MHz Scintillation Measurements. (It shows strong seasonal control. While only weak scintillations are observed in summer, a broad maximum extends from the fall-to-spring equinox.)

optical imaging systems has been especially useful in studying the spatial extent of bubbles and their motion relative to both the ground and to the surrounding ambient ionosphere. Bifurcated bubbles were observed for the first time at Ascension Island during January, 1981.

Model studies were carried out to specify the ionospheric conditions and electrodynamical processes required to describe the geometry of westward tilting and bifurcating equatorial plasma depletions inferred from airglow imaging measurements taken on Ascension Island in early 1981. The results indicated that if the westward tilts were to be associated with eastward plasma drifts that decreased with altitude above the F-peak, this shear must be set up by a zonal wind pattern of decreasing speed at increasing distances from the equator. Below the peak, calculations of flux tube integrated Pedersen conductivity, including both E- and F-region contributions, were in agreement with earlier work that showed bifurcated depletions to be associated with a mild gradient in the bottomside conductivity profile.

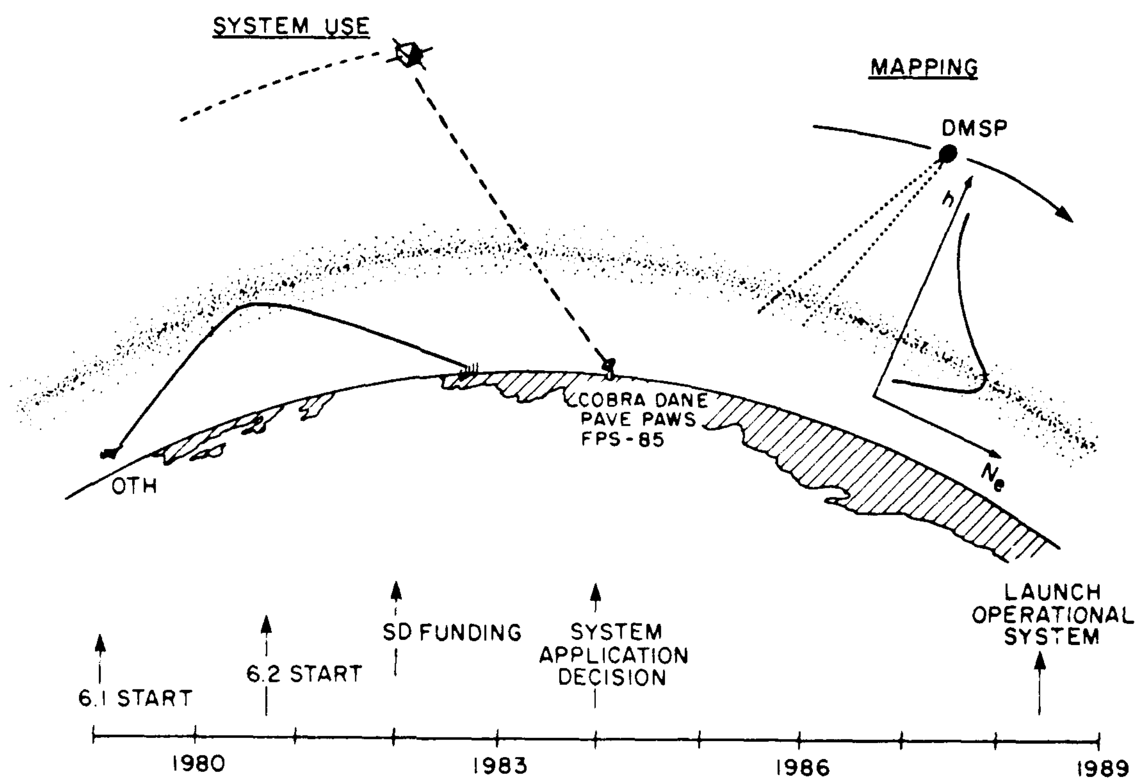
Modeling Total Electron Content: Analysis of Faraday rotation (136 MHz) measurements between Ascension Island (8° S geographic latitude; 345° E geographic longitude; 15° S dip latitude) and the Sirio satellite (azimuth 0°, elevation 80°) reveals two characteristic features associated with the undisturbed, ambient ionosphere: a late afternoon decrease in TEC followed by a postsunset enhancement that lasts for 2 to 3 h. The ambient ionosphere above Ascension Island was investigated by numerically solving the time-dependent plasma continuity equation, including the effects of ionization production by solar ultraviolet radiation, loss through charge exchange and transport by diffusion, E × B drift and neutral wind (both zonal and meridional components appropriate for an equinoctial, solar cycle maximum period). The postsunset enhancement in upward E × B drift, which is a characteristic feature observed by the Jicamarca incoherent scatter radar facility during solar cycle maximum periods, was found to be primarily responsible for the postsunset increase in TEC observed at Ascension Island between 1900 and 2300 LT. The late afternoon decrease in TEC is caused by an increase in the poleward neutral wind velocity, which lowers the F-layer into a higher loss-rate region. Inclusion of the

meridional wind not only reproduces the observed decrease but also modulates the postsunset peak in TEC so that it is in much better agreement with the observed values. Calculated north-south asymmetries in TEC caused by a zonal wind component were also consistent with observation.

Ionospheric Electron Density Profiles from Satellites: In FY 79 a basic research effort entitled "Remote Ionospheric Mapping" was established at AFGL with the support of the Air Force Office of Scientific Research. The objective of the work for the first two years was to conduct basic research studies designed to give us an understanding of how the ionospheric electron density profile was related to other ionospheric properties. At that time such an understanding was lacking.

As a result of these studies, AFGL in cooperation with Space Division developed a concept for determining global electron-density profiles (EDP) from remote, passive satellite measurements. Studies were conducted of the relationship between ionospheric optical emissions and E- and F_1-region EDP and plasma-transport processes and their effect on the F_2-region EDP. Also, a semi-empirical computational model which uses real-time ultraviolet, total electron content, and other data to adjust the calculated EDP for realistic conditions was developed. The study has been translated into a system concept for use on the DMSP satellite to provide the global electron density distribution for support of hf communications, over-the-horizon and spacetrack radar and other DoD customers (see the figure). The system concept comprises the

IONOSPHERIC ELECTRON DENSITY MAPPING



Overall Systems Concept for Ionospheric Electron Density Mapping from DMSP satellite

design, construction, and installation of a UV sensor on the DMSP satellite; the development of an associated automatic data processing (software) system; the use of the optical data together with DMSP electron density and temperature data to deduce the real-time EDP near the satellite orbital plane and the transmission of these EDP data to be used together with ground-based ionosonde data and GPS Total Electron Content (TEC) data to specify the global EDP for system users. The system is designed to monitor the daytime low- to mid-latitude ionosphere from 90 to 1000 km, the nighttime mid-latitude ionosphere from 250 to 1000 km, and the auroral E layer from 90 km to about 200 km.

The system concept makes use of state-of-the-art satellite measurements of optical emission features and computer codes developed to convert the emission measurements into electron density profiles. In the daytime low- to mid-latitude ionosphere, no useful optical emission features have been identified which when measured from the DMSP altitude (~ 840 km) give a signal directly dependent upon the electron density profile. In this region, we will therefore use an indirect method to measure the emission feature at 1356 A and at least one of the Lyman-Birge-Hopfield (LBH) bands to deduce the O to N_2 density ratio and the absolute scale of the solar flux. This information together with a neutral wind model is used to calculate the EDP from first principles using time-dependent ion continuity equations. Basing the specified EDP on the key parameters (O to N_2 density ratio and scaling factor for the solar flux) significantly improves the accuracy of the EDP over a result based on empirical values of these parameters.

In the nighttime mid-latitude ionosphere there are at least two usable emission features which give a signal directly dependent on the electron density profile. They are the atomic lines of excited OI at 1356 A and 6300 A. These relate sensitively to the electron content near the peak of the EDP and the altitude of the bottomside EDP, respectively. To extract the most accurate EDP from these observations, we are currently investigating two approaches: (1) a time-dependent transport approach where the neutral winds and, possibly, the electric field are deduced from the optical emission measurements, and (2) an empirical model where the shape of the F layer is fixed and its altitude location and its absolute value are determined by the emission features. This would produce F-layer profiles from about 250 km to 1000 km.

In the auroral E-layer, in the absence of arcs, we can use the emission features at 1356 Å and one or more of the LBH bands to give an indirect determination of the hardness and energy flux of the incident auroral electrons which produce the E-layer. The EDP from 90 km to about 200 km is then determined by using this incident electron information in our electron transport/chemistry model. Implementation of the concept requires an improvement of present EDP modeling theory.

Solving Linearized Plasma Kinetic Equations with Collisions: In 1946, Landau gave a method for solving linearized plasma kinetic problems where discrete particle interactions were neglected. Subsequent studies of collisional plasmas have employed methods of solution tailored to a specific form for the collisional operator. In 1984, Jasperse and Basu gave a general expansion method for solving linearized plasma kinetic problems when collisions are included. The method can be applied to a wide class of collision operators and has, for example, produced closed-form results for the collisional dielectric function for the Balescu-Lenard collision operator.

The essence of the idea presented by Jasperse and Basu is the derivation of a collisional propagator in terms of the collisionless propagator for the Vlasoc equation and the linearized collision operator, and the representation and use of the collisional propagator either as a series solution in powers of the collision frequency ν

or as an asymptotic expansion as the collision frequency tends to zero.

When the Balescu-Lenard operator is used to describe electron-electron and electron-ion collisions, and when the zero-order distribution function is Maxwellian, we obtain an exact expression for the collisional correction to the Landau damping formula in the long wave-length limit to the first order in the plasma parameter. This accomplishes a goal that had frustrated plasma physicists for the past four decades.

Geomagnetic Storm Prediction: Geomagnetic storms and auroral activity are caused by large-scale electric currents surrounding the earth and are known to disrupt several defense systems. The magnetic fields produced by the fluctuating currents are identified as the geomagnetic storm fields. These large-scale disturbances result from the interaction of solar wind plasma with the magnetosphere and with the energy transfer strongly controlled by the instantaneous Interplanetary Magnetic Field (IMF) near the earth. The auroral oval is an optical manifestation of these processes; the auroras are caused by collisions of current-carrying electrons with the polar upper atmospheric atoms and molecules.

Possible means of reducing the negative consequences of this hazard are: (1) to forecast accurately the intensity of geomagnetic storms and auroral activity as a function of time soon after a major solar event, (2) to forecast the resulting ionospheric disturbances and system effects, (3) to alert all defense systems which are vulnerable to geomagnetic storms and auroral activity, and (4) to mobilize emergency systems. Thus, the accuracy of forecasting the occurrence and intensity of geomagnetic storms and auroral activity as a function of time is of high importance in reducing expenses involved in mobilizing the emergency systems. This implies that the present forecasts based on statistical analyses must be considerably modified to utilize numerical schemes similar to numerical weather forecasting.

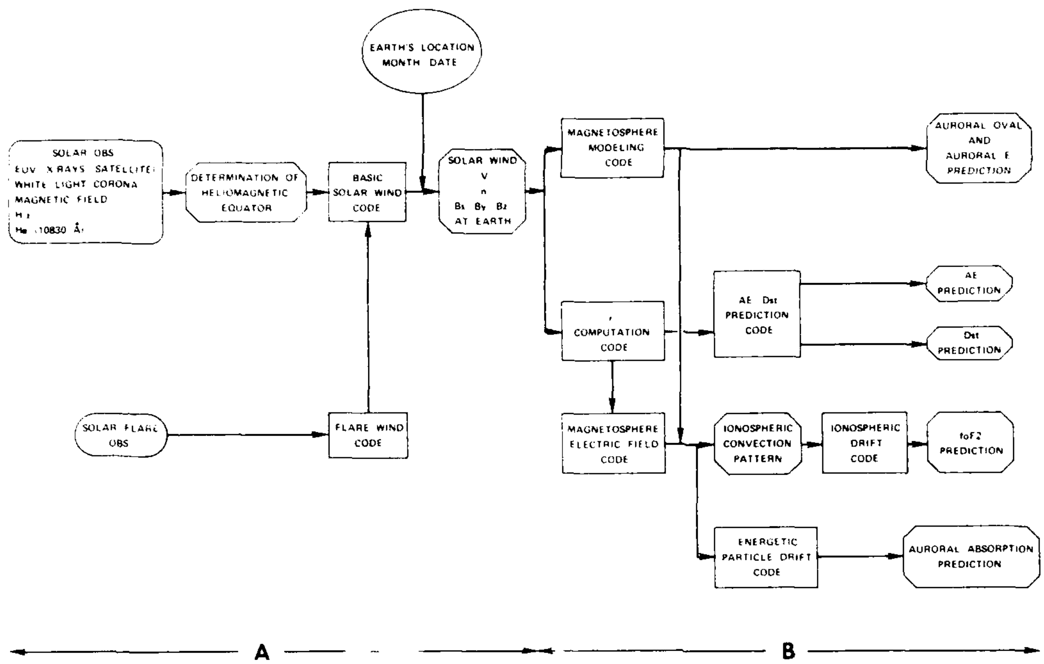
Under an AFGL contract, a major code for the improvement of geomagnetic storm forecasting has been developed by the University of Alaska, based on the understanding of the three-dimensional structure of the interplanetary field and its dynamics, and of the energy transfer function $\epsilon = f(v, B^2, \theta)$, which describes the energy transfer from the solar wind into the magnetosphere as a function of v, the solar wind speed; B, the IMF magnitude at the bow shock; and θ, the polar angle between the IMF vector and the plane of the ecliptic.

The overall scheme is shown in form of a functional flow diagram in the figure. Major sections of the code have been completed and interconnected. It is now possible to establish the background solar wind/IMF conditions in the vicinity of the earth, initiate a solar disturbance (such as a flare, passage of a coronal hole, or a disappearing filament), and derive the time history of the resulting geomagnetic storm (see the figure). The development of other subsections of the code, such as the magnetospheric modeling code, which provides the open/closed field line boundary and the ionospheric drift code, important to the maintenance of the polar cap ionosphere and the development of the trough, and irregularity generation and transport have been completed.

The magnetosphere modeling code was tested using different interplanetary magnetic field parameters (BZ, ϕ, θ) to determine the shape of the auroral oval. An ionospheric drift code was constructed which uses the power of the solar wind-magnetosphere dynamo, ϵ, as an input parameter. The geometry of the solar current sheet under various conditions (constant solar latitude, varying solar longitude) has been simulated.

The propagation characteristics of shock waves generated at different locations on the solar surface have been determined as a function of solar wind speed, its growth and decay as a function of time, and the area of origin of the shock wave. The intensified geomagnetic storms have

GEOMAGNETIC STORM PREDICTION SCHEME

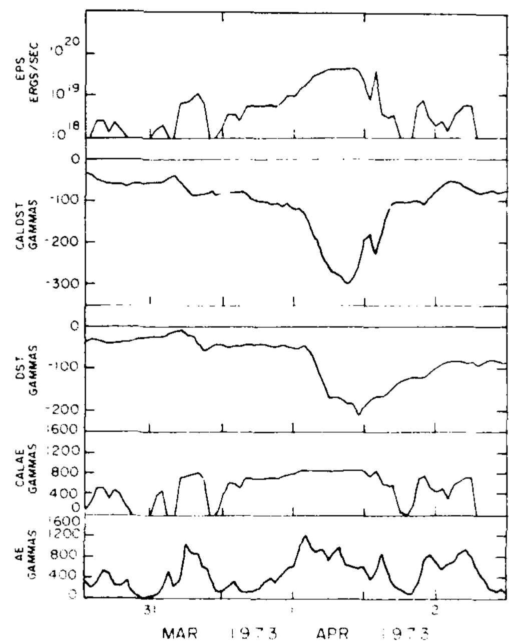


Geomagnetic Storm Predi‹ .on Scheme.
Flow-diagram of computer ; rogram.

been found to de ,end critically on ϵ, which varies as the square of the magnitude of the interplanetary magnetic field. From the simulation runs the highest magnitude of the IMF is seen to be built up when the shock wave (from the solar flare) catches up with one of the quasi-steady spiral arms. This result is a clear confirmation of the empirical fact that intense storms tend to occur during the so-called "sector crossing."

All these efforts are oriented, orchestrated, and implemented so as to promptly achieve meaningful anticipation of geomagnetic storm conditions in the ionosphere. A useful working model is targeted for 1988.

Automation of Ionogram Analysis: To reduce the continuously increasing manpower cost associated with the real-time acquisition of geophysical data by the Air Force Global Weather Central (AFGWC), and to provide for immediate true height profiles in support of rocket launches

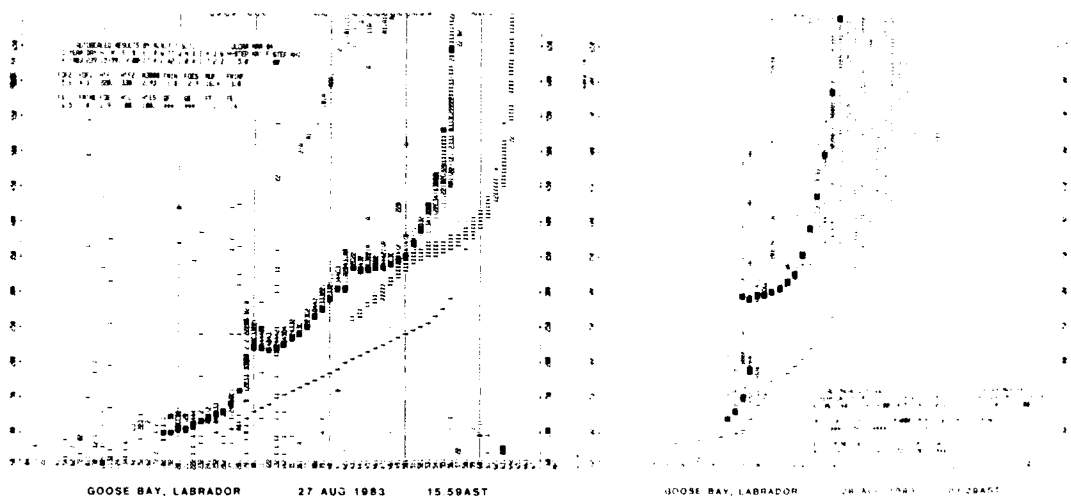


Modeling of a Geomagnetic Storm. Panel 1: Energy transfer function EPSILON, computed from ISEE-3 Solar Wind IMF data
Panel 2: Calculated D_{ST}, ring current magnitude γ
Panel 3: Observed D_{ST}
Panel 4: Calculated AE, Auroral Electrojet index
Panel 5: Observed AE

(launch criteria), AFGL started a program for the automation of ionogram analysis ten years ago. In cooperation with the University of Lowell, a hardware/software system for Automatic Real Time Ionogram Scaling with True Height Analysis (ARTIST) has been developed, and field-tested at the AFGL Goose Bay Ionospheric Observatory. The algorithms are capable of extracting the desired information from typical mid-latitude ionograms as well as from the typically disturbed arctic night-time ionograms routinely recorded at Goose Bay, as shown in the figure. The ARTIST extracts the overhead tract for direct transmission to over-the-horizon operations site, as well as for true height analysis. The ARTIST also extracts the standard ionospheric parameters and formats the trace and parameter data into "IONHT" and "IONOSCODE" messages for real-time transmission to AFGWC. This automation of the trace identification also makes possible the adaptive frequency and sample height selection necessary for unmanned ionosonde drift measurements. These will be conducted in the near future at Qanaq, Greenland, Goose Bay, Labrador, and Argentia, Newfoundland, to measure routinely the high-latitude plasma convection.

OTH-B Support: Rapid changes in foF2 of greater than 20 percent per hour are routinely observed during a 3 h to 4 h period around F-region sunrise. These rapid changes occur independently of the phase of the solar cycle. The changes can be as high as 50 percent per hour near solar maximum (see the figure). For the frequency management of an over-the-horizon system, these rapid changes translate into the need for an improved short term foF2 prediction scheme. Such a scheme has been developed. The scheme makes use of real-time hourly ionospheric soundings and extrapolation using a weighted median slope obtained from previous measurements.

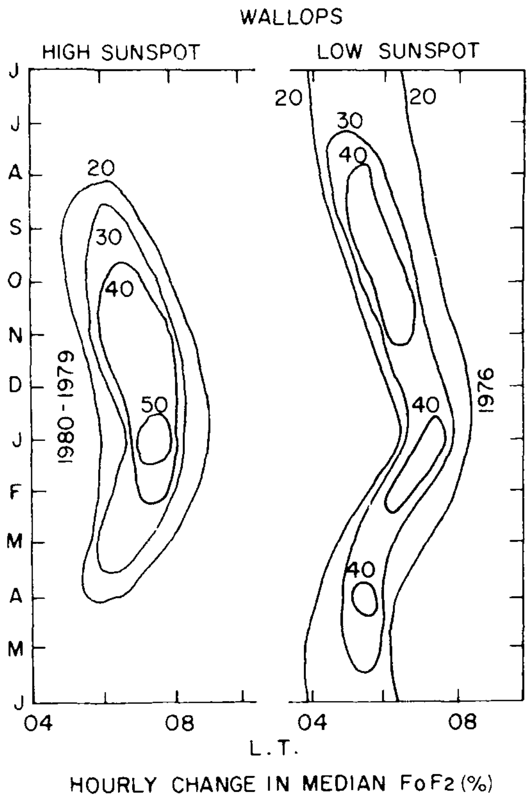
To simulate the ionosphere relevant to the OTH-B East Coast Radar System, the scheme was tested for five stations: Narssarssuaq, St. Johns, Ottawa, Boulder, and



A.R.T.I.S.T.

AUTOMATIC REAL TIME IONOGRAM SCALING WITH TRUE HEIGHT ANALYSIS

Automatically Scaled Ionograms. (Left: daytime; Right: nighttime auroral conditions. ((True height profiles. Upper left and lower right inserts: Autoscaled results, ionospheric parameters.)



Hourly Change in Median foF2 at Wallops Island for High and Low Sunspot Activity.

Wallops. Predictions were tested for four seasons and for periods of high and low solar activity.

The results show that the new prediction scheme reduces the prediction error by 40 percent over that from the IONCAP model. The use of this new prediction scheme will thus reduce the error in foF2 predictions by a factor of 2 for the OTH-B coverage area, and will enable better management of the radar frequency for sunrise hours.

JOURNAL ARTICLES JANUARY, 1983 — DECEMBER, 1984

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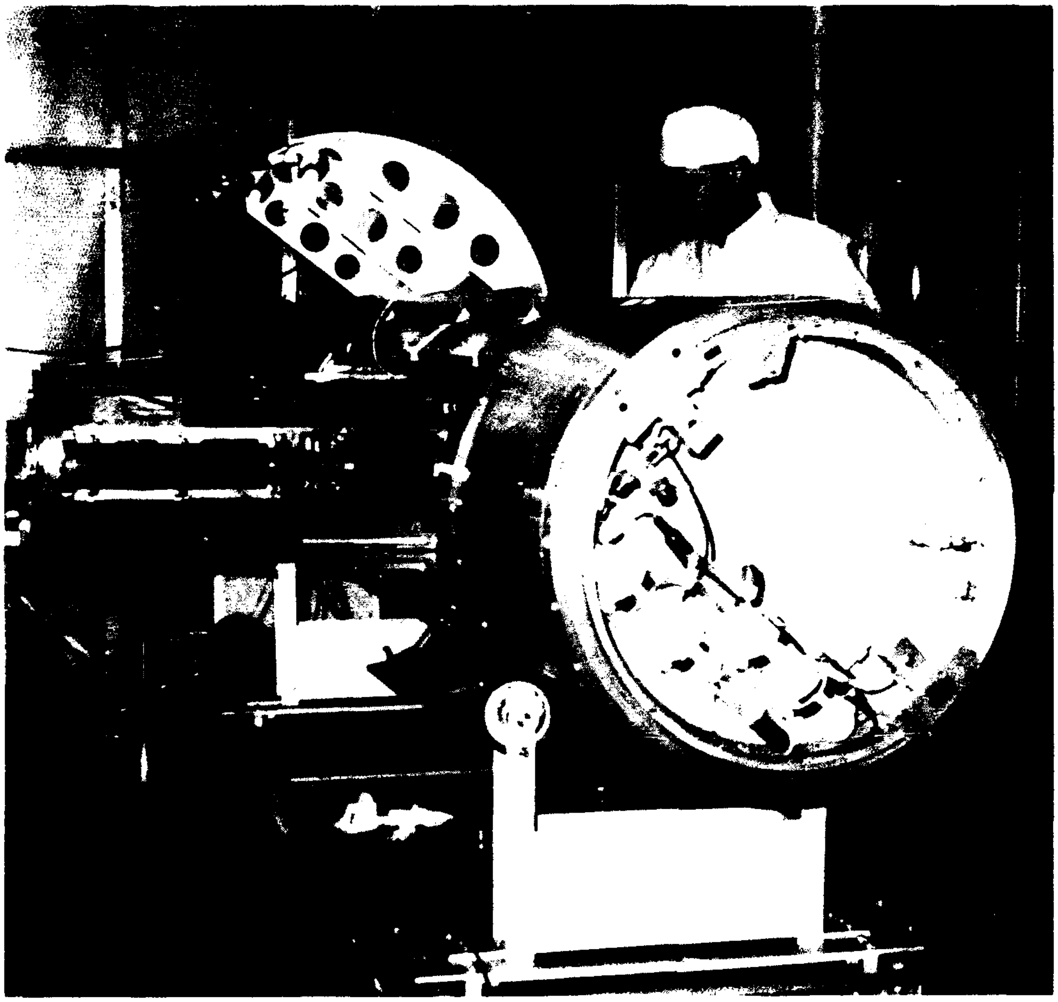


Earth Limb Clutter Payload, ELC-1, Undergoing Tests in the AFGL Clean Room. (The infrared telescope is shown extended out of the payload as it is deployed in flight.)

III AEROSPACE INSTRUMENTATION DIVISION

The Aerospace Instrumentation Division supports the other divisions of AFGL by providing probe vehicle systems—balloons and sounding rockets—to carry the instruments that gather data for scientists in their studies of the environment. Our engineers also manage Laboratory-initiated experiments to be flown on satellites of the Air Force Space Test Program. The use of the Space Shuttle as an experiment carrier is increasing.

To provide modern, efficient probe-vehicle systems, the Division conducts a technology base program in payload design, telemetry instrumentation and techniques, tracking, command and recovery systems. Fewer payloads are being flown than in the past, but the payloads are more complex. Increased emphasis has also been placed on reliability. Expensive sensors and payloads must now be recovered and reused. Modern solid-state sensors have an almost limitless ability to generate data. This has taxed both our airborne and ground capability to transmit and process data. Faster, more efficient data-handling is therefore a major thrust of our technology base program.

We can conduct rocket and balloon flights from anywhere in the world. A majority, however, are flown from White Sands Missile Range, New Mexico, where restricted air space, optical tracking, precision radar, and excellent conditions for payload recovery are available. Rockets are launched from a Navy facility at White Sands Missile Range shared with other users. Balloons are launched from a

permanent balloon-launch facility at Holloman AFB, within the White Sands Missile Range, manned by AFGL Detachment 1.

BALLOON PROGRAM

The Balloon branches of the Aerospace Instrumentation Division design and develop completely instrumented, large balloon systems for in-situ measurements in the stratosphere and developmental tests of instruments intended for space operation. The experimenters are scientists from the other AFGL Divisions, Systems Command, agencies in the Department of Defense, and other government agencies.

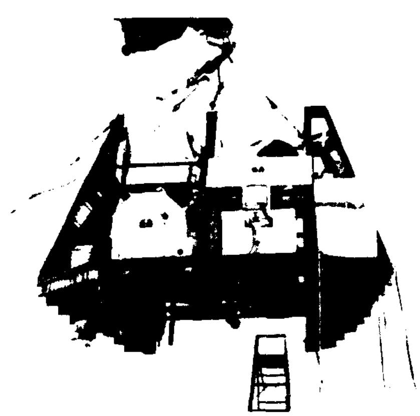
The balloon program manager works closely with the scientific investigator from the inception of a balloonborne experiment. Their collaboration ensures that all components of the payload will be environmentally suitable, and the balloon instrumentation will in fact provide the electrical power budget, data-handling capability, radio-command facilities, flight trajectory, and payload-recovery operations required to fulfill the experimental objectives.

Mammoth free balloon systems, unlike other probe vehicles, ascend slowly, typically at 800-900 ft per minute, and can remain aloft for hours, or even for days if so designed. Payloads can be almost any size or shape that can be handled at the launch site. Instruments can be reeled down, and up again, thousands of feet below the balloon whenever the investigator so commands. Small packages or individual sensors can be placed on top of the balloon.

Many AFGL flights are launched from our Balloon Facility at Holloman AFB, New Mexico, on the White Sands Missile Range. Our mobile facilities are used to launch from remote locations, or from strategically-located, off-base sites chosen so that the local wind fields will carry the balloon directly over a designated test area.

Microelectronics and today's computer technology have vastly improved the options available to balloon experimenters. Heavy, delicate, complex instruments are being flown and recovered for reuse. While a flight is in progress, selected data are reduced immediately and displayed at the control center for quick-look appraisal in whatever format the experimenter has specified. Up to several hundred interference-free radio commands are available to alter or manipulate the experimental controls in the payload. AFGL is exploiting these capabilities by flying innovative payloads to obtain first-time measurements having immediate applications to scientific and military needs, as indicated below.

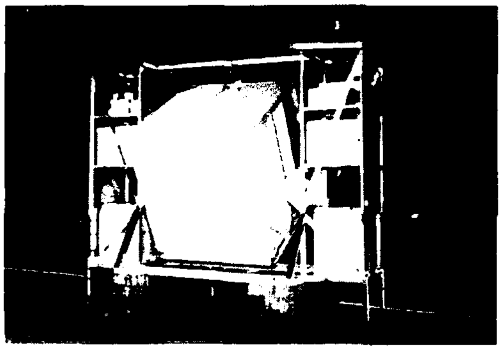
ABLE: The Optical Physics Division's balloonborne lidar system, for example, flown in 1984, carried a laser, a telescopic receiver, and rotatable pointing mirrors (see the figure) so that back-scatter measurements could be collected from directions as commanded from the ground station (see Chapter VII). These lidar measurements, over an extended range, were the first to be made from stratospheric altitudes. During the flight, lidar data first were recorded from the atmospheric regions above the balloon. Later, from the



Balloonborne Gravity Gondola Includes a Balloon-motions Payload with 3-axis Gyros and Accelerometers Developed under Project 7659 to Record the Local Motions of Orientation or Rate-sensitive Payloads.

restricted air space above the White Sands Missile Range, down-looking observations were made within the particulate-carrying atmospheric volume between the balloon and the ground. This flight demonstrated the autonomous operation of a laser, including harmonic generation, in a space-like environment, and established quantitatively the range-dependency of lidar data recorded from a location nearly outside the earth's atmosphere. This information is highly relevant to the development of future space-based systems.

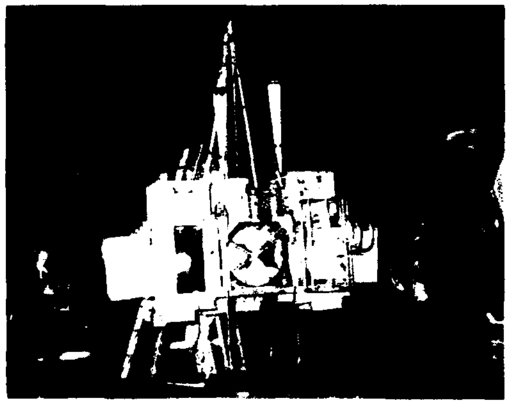
SCRIBE: This balloonborne interferometer experiment gathers high-resolution infrared spectral measurements from stratospheric levels (see the figure). The



The Aerospace Instrumentation Division managed this balloonborne operation carrying a gamma-ray experiment for the Air Force Technical Applications Center (AFTAC).

Optical Physics Division's instrument observes absorption and emission characteristics along the horizontal and down-looking atmospheric paths through which long-range target-detection systems must view (see Chapter VII).

Ashcan: In 1983-84, the Aerospace Instrumentation Division continued the Ashcan balloon program to obtain air samples in the stratosphere for the Health and Safety Laboratory of the Department of Energy. Three separate air-sampling devices were flown in January, 1983, to provide background measurements just before the anticipated reentry of the Soviet COSMOS satellite (see the figure). This mission was planned and executed with only two weeks' prior notice. The post-reentry samples were taken in February, 1984, when the COSMOS radio-active debris was forecast to be drifting in the stratosphere above Mew Mexico. In March, 1984, sulfate sampling was added to the long-term program to collect nuclear debris and carbon-14 samples.



This ASHCAN payload carried an air ejector sampler for the higher altitudes, a direct flow type for mid-altitudes, a cassette for three different samples, and an impactor sampler.

Balloonborne Gravity Measurements: Values of gravity at high altitudes are estimated from models having unverified accuracies. This deficiency can contribute to significant guidance errors. The Earth Sciences Division's Balloonborne Gravity Measurements Program is flying a gravimeter to obtain precise measurements of acceleration due to gravity in the stratosphere (see Chapter VI). These new data should lead to significant reductions in the miss errors on the test range or at operational missile launch sites. A first engineering flight was made in October, 1983. A second flight with improved sensors is planned for October, 1985.

Galileo: Stratospheric balloon flights are a cost-effective means for observing the performance of planetary probes. By releasing a probe vehicle at a predetermined altitude (air density) and then

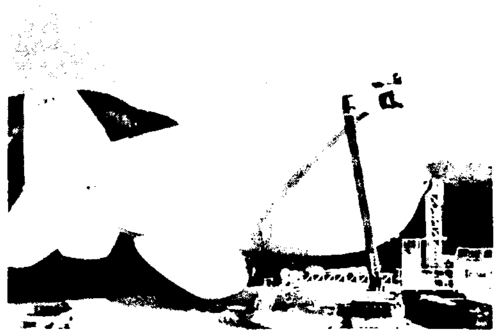
accelerating it to an altitude-related velocity, a working simulation of the actual planetary environment of the probe is created in the stratosphere. Galileo is the latest of several AFGL planetary-entry balloon programs. The tests for NASA simulated descent speeds and decelerations that will be encountered when the Galileo probe enters the atmosphere of Jupiter. The probe was dropped from 97,000 ft above the White Sands Missile Range. Camera-equipped telescopes and radar recorded the probe separation and parachute deployment and descent.

Tethered Balloons: The Aerospace Instrumentation Division also has a working inventory of large tethered aerostats. They are quite regularly used for atmospheric measurements, surveillance exercises, mounting targets for advanced radar and weapons qualification, and dropping modules to observe their performance before space operation. The balloon groups are also developing new, dedicated tethered systems for special military applications. These new systems use computer-designed aerostat shapes that fly with good stability in very high winds, and new lightweight, strong hull materials and cables. For communications and other long-endurance applications that should not be interrupted to replenish the power supply, tether cables are now being designed to incorporate an electrical conduit that delivers power from a ground-based source up to the payload.

Tethered Aerostat Antenna Program (TAAP): At the request of the Defense Communications Agency, AFGL balloon specialists have developed and produced a proof-of-concept, completely mobile tethered system to reconstitute lf/vlf communications among strategic forces. The Rome Air Development Center provided guidance for the transmitter and antenna aspects of the system. The aerostat-supported, high-powered antenna is an integral part of the 3000 ft tether cable.

In November, 1984, this TAAP system participated in a world-wide vlf transmission test organized by the Defense Communications Agency. During these tests, AFGL demonstrated very successfully the ability of the TAAP system to broadcast to a network of military stations including SAC aircraft, submarines and units off the California coast and in Europe.

North Warning System: The North Warning System Program Office of the Electronic Systems Division asked AFGL to investigate the feasibility of operating large tethered aerostats routinely in the Arctic as surveillance platforms at selected Distant Early Warning (DEW) Line locations on the Davis Strait. A scaled-down mobile tethered system was modified for cold weather operation and a three-month field test program was conducted during the winter of 1983 at Fort Ethan Allen, Vermont (see the figure). In October, 1983, a staff meteorologist and two AFGL balloon specialists visited selected DEW Line stations on the Davis Strait.



Sub-Arctic Field Tests. (Application of a de-icing compound to 25,000 cu. ft. aerostat at Ft. Ethan Allen, Vermont. Several ice-removal techniques and ice-inhibiting compounds were tested during blizzards.)

The sub-Arctic test program in Vermont has demonstrated the feasibility of conducting aerostat operations in moderately severe cold and heavy snow. Operational limitations caused by icing on the aerostat and tether cable were clearly identified. The Davis Strait climatological data have been thoroughly analyzed and the need for additional data identified. A mooring sys-

tem for a 365,000 cu ft aerostat to fly on station in the Arctic has been designed on paper. Possible solutions to the icing problem have been investigated, but no definitive answer has been found.

SRHIT: AFGL is flying a 100,000 cu ft tethered aerostat carrying a missile target on the White Sands Missile Range for the U.S. Army in the Small Radar Homing Intercept Technology Program. The 48-in spherical target must remain positioned within a prescribed intercept scoring box at 12,000 ft altitude above ground. This is accomplished by using a modified M47 Patton tank as the tethered ground anchor and moving the tank as required to compensate for changes in the wind direction.

Balloon Systems: During 1983-84, the balloon groups continued in-house studies and hardware development to modernize and improve AFGL balloon instrumentation and vehicle capabilities.

A new multi-address digital command system provides independent address and status verification for up to 855 commands, secure from interference that produces false commands. It is operable with every hf, uhf and vhf radio frequency assigned to AFGL.

A payload motions package contains sensitive three-axis gyros and accelerometers to measure the very small rotations and vibrations of gondolas carrying orientation- or rate-sensitive instruments. The data are also needed for designing pointing controls and stabilized platforms.

Pathfinders are new, 140,000 cu ft, zero-pressure balloons carrying a meteorological sensor package and an Omega tracking system. Unlike sonde vehicles, they float for several hours at 120,000-140,000 ft levels and thus indicate the most probable balloon trajectory due to the upper level winds. Pathfinders are launched just prior to the scheduled launch of critically important experiments that must overfly a predetermined test area.

A theoretical study to predict balloon ascent trajectories has demonstrated that the aerodynamic drag coefficient of an ascending balloon cannot be based solely on the Reynolds number, but rather must depend also on the Froude number and fractional volume.

SOUNDING ROCKET PROGRAM

The Sounding Rocket Branch of the Aerospace Instrumentation Division is responsible for the development, management and launch of rocket-payload systems for AFGL's research rocket program and for the integration of AFGL experiments on free-flying and Shuttle-based spacecraft (see Appendix B for specific flights during the reporting period). With a history that includes the instrumenting and launching of more than 1000 sounding rockets since 1946, the high rate of successful launches continues.

In 1983, twelve sounding rockets were launched in support of AFGL scientists. Two failures occurred on rockets because of non-ignition of the second stage. All payload systems performed nominally. Five sounding-rocket programs started development in 1984 and are scheduled to be flown in 1985. About one-half of the technical effort normally applied to research rocket work is now devoted to satellite and Shuttle payload system integration. In the report time period, experiments were flown on two free-flying satellites and three Shuttle flights.

We continue to provide support to experimenters by selecting launch vehicles; designing, fabricating, and integrating experimental payloads; conducting test and launch operations; and providing for telemetry and trajectory data collection. As scientific requirements lead to the evolution of more sophisticated payloads, both the size and complexity of payloads continue to increase. Payloads exceeding 1500 pounds, such as those flown on Aries type rockets, have become routine. Increased data-handling requirements have led to the use of computer-based technology in both airborne and ground-based support systems. The need to continually advance the state of the art of rocket in-

strumentation has required a corresponding emphasis on our in-house engineering development program.

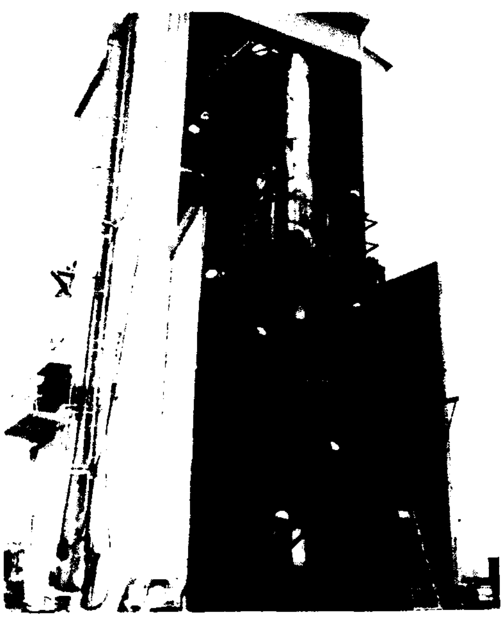
Technology based research has continued in the areas of micro-processor-based adaptive telemetry systems, intelligent data processor systems and command and control systems. A base line design was developed for a multi-use spacecraft detached from the Shuttle. Utility and cost comparison show this could be a viable option to the present high-cost Shuttle payload system.

Background Measurements Program: The final mission of this Space Division program was successfully conducted in October, 1983, from White Sands Missile Range. An Earth Limb Clutter payload was flown on an Aries rocket to gather data on the infrared characteristics of the earth limb (see the figure). The payload flew to an apogee of 282 km, gathered much important data, and was successfully recovered by parachute on the same day. The entire background measurements program was an unqualified success. Five of the six missions flown since 1980 met their intended objectives and were recovered for future use. All missions were flown on the Aries rocket system.

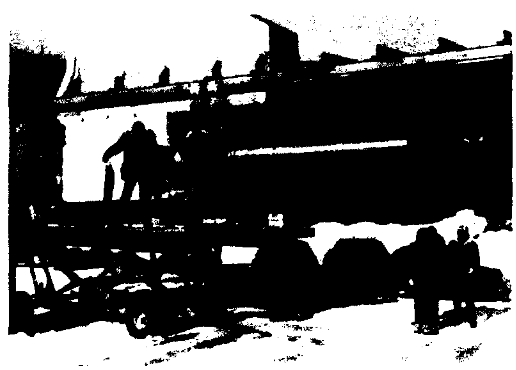
Auroral Program: AFGL continues an active auroral research program using sounding rockets flown from the Poker Flat Research Range located north of Fairbanks, Alaska. Six rockets were instrumented and launched into various types of auroral events. These missions supported both the AFGL exploratory research program and Defense Nuclear Agency requirements.

In March, 1983, AFGL flew the highly successful Earth Limb Infrared Atmospheric Structure payload. This 1500 lb payload flew on a Talos-Castor rocket to an apogee of 305 km and acquired the first infrared data of an active aurora on the earth limb. Another first occurred one month later in April, 1983, when the first successful Field Widened Interferometer flew on a Sergeant rocket to its planned 130 km apogee (see the figure). This payload was recovered in excellent condition and is being refurbished to fly again in 1985.

In June, 1983, AFGL conducted the Structure and Atmospheric Turbulence Environment (STATE) program from Poker Flat, Alaska. Four sounding rockets were launched along with a half-dozen



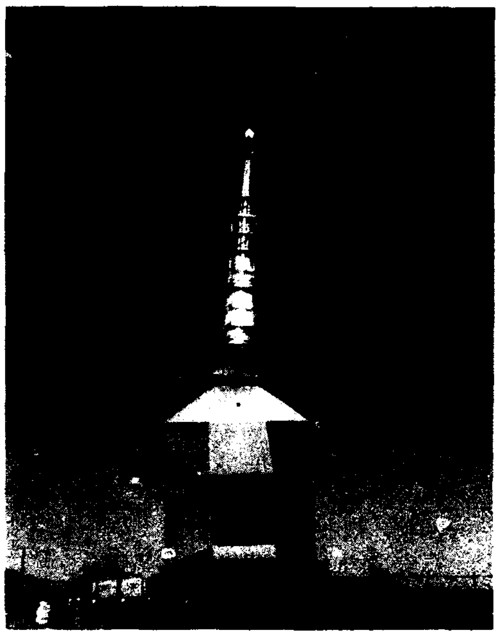
ELC-1 Being Readied for Launch on its ARIES Booster at White Sands Missile Range, New Mexico. (The clean payload remains enshrouded in plastic until just before launch.)



The Field Widened Interferometer payload is shown on the launch rail at Poker Flat Research Range, Alaska.

meteorological rockets on three salvos on three consecutive days to perform in-situ measurements of the dynamical properties of the atmosphere in the 30 km to 130 km altitude range.

Last Aerobee Rocket: In April, 1983, an ultraviolet spectrometer was flown from White Sands Missile Range to an apogee of 200 km on the last liquid-fueled sounding rocket on the AFGL schedule, an Aerobee 170 (see the figure). Over 1000 Aerobees have probed the sky in their 36-year history, about 275 of them launched by AFGL. The high cost of servicing liquid-fueled rockets, coupled with the availability of surplus military solid-propellant boosters, made this highly successful rocket obsolete.



The last AFGL Aerobee 170 rocket leaves the launch tower at White Sands Missile Range, New Mexico.

Sensor Eject System: In March, 1983, the Sounding Rocket Branch showed its quick-reaction capability by launching the complex Sensor Eject System payload for Space Division less than 12 months after the program was conceived. First funding for this complex mission was received on 19 April 1982. The 650 lb payload was designed, the Space Division experiment integrated, and the mission successfully flown and recovered on 1 March 1983 (see the figure).

An Astrobee F Rocket is placed on its transport/launch rail at White Sands Missile Range, New Mexico, for the Sensor Eject System mission.

Space Shuttle Systems: Much of the work of the Sounding Rocket Branch has evolved into Shuttle payload systems. Three payloads were flown on the Shuttle during the reporting period. On the third, the Sounding Rocket Branch integrated two experiments on the first flight of the NASA Long Duration Exposure Facility (LDEF) on STS Mission 13 on 6 April 1984. The AFGL experiments were the first to be qualified by NASA. The LDEF is scheduled to be retrieved by Discovery during the 19-24 March 1985 Mission 23.

Technology Base Development: The increased emphasis on the use of the Space Shuttle has required us to direct our technology-base research program toward Shuttle support systems. Fortunately, many of the improvements in state-of-the-art technology are a direct evolution of sounding-rocket systems technology.

Profiting from our long experience in the development of highly accurate, megabit PCM encoders, we undertook the development of intelligent, command and control data processors for Shuttle experiments. A prototype digital processor/controller that will process data for bandwith

reduction, provide command and control, and perform health-status checks has been fabricated and tested. This design could be used in the next generation of large experiments for the Shuttle.

An outgrowth of our sounding-rocket adaptive telemetry system was the development of a programmable PCM encoder for Shuttle Get-away Special use. The versatility of this encoder makes it ideal as the data formatter in a multi-use support system such as is being built at AFGL for a Shuttle Getaway Special mission. The use of EPROMs allows parameters such as analog input levels, digital entry channels, work length, bit rate, output code and frame formats to be reprogrammed at any time.

While an invaluable tool for space research, the Space Shuttle is also expensive. Much of that expense is the result of the complex interfaces required of an experiment on a man-rated spacecraft. The Sounding Rocket Branch undertook an investigation of the potential utility and economic feasibility of developing a standard Shuttle experiment support system to satisfy unique AFGL scientific requirements while minimizing interface with the orbiter. An excellent overall system design was generated that accommodates most all AFGL scientific requirements for Shuttle experiments. The system requires minimum Shuttle interface and has the ability to operate both in and out of the cargo bay as a closed system. A capability and cost comparison of this Shuttle Detached Spacecraft was made with all available detached spacecraft, showing that this system offered greater capability at comparable cost.

Under the long-term cooperative agreement between AFGL and the Brazilian Air Force, the Sounding Rocket Branch is involved in the development of a high-altitude reentry spacecraft and water recovery system to be employed on the Brazilian SONDA IV rocket. This system will enable an 850 lb payload to be successfully recovered from a 1000 km apogee flight. The spacecraft will be flown from Natal, Brazil, in FY 85.

At present, AFGL's infrared telescopes are limited to operating at temperatures no colder than the 6°K vapor temperature of liquid helium. In FY 84 a technology-based development was initiated for a space vacuum assisted passive super-fluid helium cooler that would enable a quantity of 2°K liquid helium to be generated for focal plane cooling in space. This development will be tested on the SONDA IV rocket mission in FY 85.

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Processor-Controlled DAC-20
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KOZUMA, R., COX, E., ENGEL, H., GREENWOOD, W., HAMANN, R., and JOHNSON, R. (Analytical Systems Engin. Corp., Burlington, MA)
Engineering Services in Support of the AFGL Sounding Rocket Programs
AFGL-TR-83-0127 (25 March 1983), ADA131929

POIRIER, N.C., and WHEELER, T.P. (Northeastern Univ., Boston, MA)
Remote Data Acquistion System
AFGL-TR-84-0115 (1 April 1984), ADA143347

ROCHEFORT, J.S., O'CONNOR, L.J., POIRIER, N.C., and WHEELER, T.P. (Northeastern Univ., Boston, MA)
Signal Encoding and Telemetry Systems for Space Vehicles
AFGL-TR-83-0135 (1 May 1983), ADA134445

SHAW, H.L., and TERWILLIGER, D.F. (Physical Science Lab., Las Cruces, NM)
Feasibility Study for an AFGL Fiber Optic Data Link at WSMR Sounding Rocket Launch Area
AFGL-TR-84-0292 (1 October 1984), ADA [in process]

TERWILLIGER, D.F. (Physical Science Lab., Las Cruces, NM)
Engineering and Instrumentation Support of the AFGL Research Rocket Program
AFGL-TR-83-0189 (27 July 1983), ADA [in process]

WEINSCHEL, H.D., and WATERMAN, A. (Physical Science Lab., Las Cruces, NM)
Cylindrical Microstrip Array - C-Band Beacon Antenna with 48 Rectangular Radiating Elements Fed In-Phase
AFGL-TR-83-0218 (July 1983), ADA135144
Antenna Performance Verification at Launch Site - A Feasibility Study on Preflight Performance Testing of Stripline Slot Arrays Mounted on a Rocket
AFGL-TR-84-0069 (January 1984), ADA143266

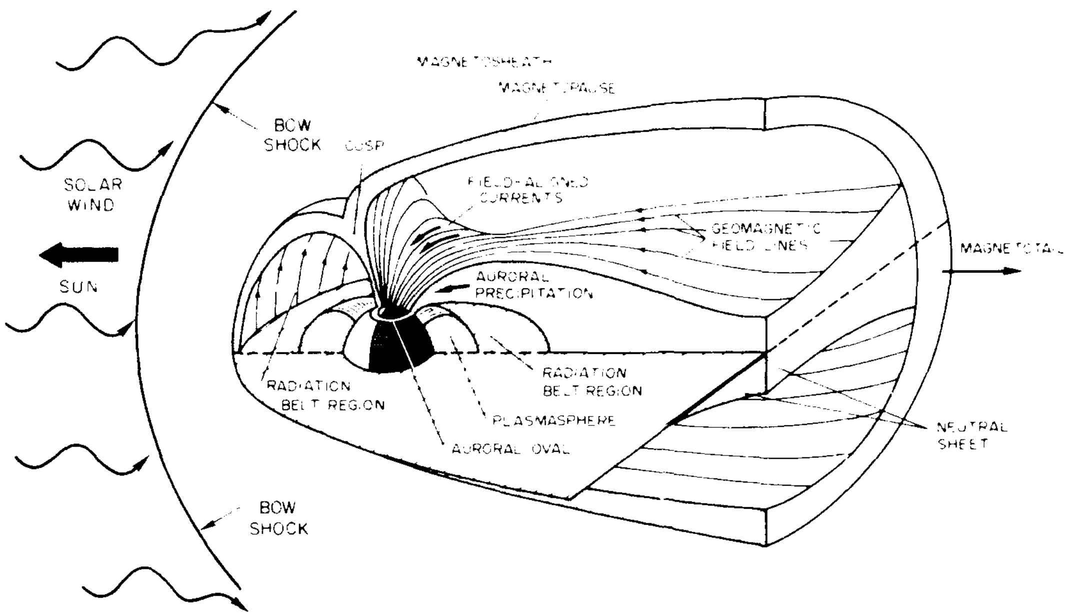
Looking up at a Sounding Rocket Payload Suspended from the Roof of a Cylindrical Space-simulation Vacuum Chamber (approximately 60 ft by 100 ft). (A plasma similar to the ionosphere is created inside the chamber while a beam of ions and electrons is emitted from the payload. The charging of the spacecraft in these conditions is then recorded. The white thermal curtains in the background protect the payload from the walls, which reach a temperature of 10 K.)

IV SPACE PHYSICS DIVISION

Basic research and exploratory and advanced d_velopment in the solar-terrestrial system are crucial to the development of future Air Force space systems. The results contribute to the survivability, reliability, and autonomy of new space systems, to space weather forecasting for space operations, and to the optimum performance of command, control, communication, and intelligence (C^3I) systems.

The sun is the primary source of energy in the solar-terrestrial system. Understanding the physical mechanisms responsible for solar emissions is essential to the success of Air Force space programs. The Solar Research Branch of the Space Physics Division studies fundamental solar processes, including the emission of electro-magnetic radiation, energetic protons, cosmic rays, and the solar wind. The solar wind determines the shape and size of the magnetosphere-ionosphere cavity (see the figure), as well as the energetic particle content of the magnetosphere. The solar flare is the most striking example of solar disturbances which can produce catastrophic effects on Air Force space systems.

Most Air Force space operations are carried out within the ionosphere-magnetosphere system, as shown in the figure. The outer boundary, the bow shock, is located approximately 10 earth radii upstream from the earth along the sun-earth line. The inner boundary is identified as the base of the ionosphere E-layer at approximately 100 km. Within this system, regions of great importance to Air



Model of the Magnetosphere Showing Major Particle Populations.

Force operations are the earth's radiation belts and the high-latitude regions, including the auroral zone and polar cap. Scientists in the Space Physics Division seek to understand the physical mechanisms operating in these regions and to develop a capability to model, forecast and monitor ionosphere-magnetosphere behavior. To carry out these programs, state-of-the-art space flight and ground-based diagnostics must be developed, and analytical and phenomenological models of the system derived. During the past year, considerable progress was made on the SPACERAD/CRRES program (Space Radiation Combined Release and Radiation Effects Satellite), which is designed to accelerate the transfer of new microelectronic technologies to Air Force space programs. The SPACERAD satellite will continuously traverse the earth's radiation belts. The payload includes a wide range of advanced microelectronic devices and wave particle and field sensors. This program will establish the in-flight performance of microelectronic devices, will relate causes of device degradation or failure to environmental conditions, and will generate the first dynamic models of the earth's radiation belts.

The high latitude ionosphere-magnetosphere-thermosphere region is being intensively studied by means of satellites, aircraft, rockets and ground-based instruments. Factors contributing to large-scale thermal plasma motions and the production of small-scale irregularities which produce scintillations in radio and radar signals are of special interest since they contribute to the degradation of Air Force C^3I and surveillance systems operating at high latitudes. Magnetic substorms are initiated when the energetic particles in the earth's plasma sheet and dayside cusp are suddenly accelerated along open magnetic-field lines into the near-earth environment. Studies of ionosphere-magnetosphere coupling will lead to a capability for predicting substorms and auroral and polar cap ionization. The results will contribute to models of satellite drag, auroral infrared emissions, improved frequency management and to specification of conditions under which serious signal loss and

unacceptable fade margins will develop in high-latitude communications systems.

More complex, larger, high-powered spacecraft are planned for future Air Force missions. The development of our understanding of the interactions between space systems and the environment is crucial to the proper design of these systems. Ongoing Space Physics Division programs are focused on a number of space-system environmental-interaction problems, including spacecraft charging, techniques of charge mitigation, degradation of surface materials, as well as the development of design guidelines for future space systems. Under these programs space systems environmental interactions codes and large spacecraft structure codes are being developed.

The Active Space Experiment program investigates the effects on the environment of the emissions of chemicals, waves, beams, and high-power rf signals. Theoretical developments during the past decade and advances in diagnostic sensors used to monitor the environmental effects produced by active emissions make active experiments highly feasible. This is an area of rapidly growing importance to the Air Force.

The Division program is carried out by means of in-house laboratory efforts, an extensive field program, and a broad contractual program. The field programs involve satellite experimentation and rocket, aircraft and ground-based investigations. The ground-based program includes solar studies at the Sacramento Peak Observatory in New Mexico. During the past two years, major scientific and technological advances have been made as a result of: (1) the analysis of particle, plasma, electric and magnetic field and wave instruments flown on the AF S3-2, 78-1, 78-2 (SCATHA) and DMSP F2, F4, F6, F7 and HILAT satellites; (2) solar observations from Sacramento Peak Observatory; (3) theoretical development in space simulation and auroral physics. These achievements are described in the following sections.

SOLAR RESEARCH

Solar research is performed within the Space Physics Division by the Solar Research Branch. The Branch is a tenant at the National Solar Observatory (NSO), Sacramento Peak, Sunspot, New Mexico, a national center for solar physics operated by AURA, Inc., under contract to the National Science Foundation. The primary task of the Solar Research Branch is to identify, predict, and understand those physical mechanisms on the sun that cause solar flares, high speed solar wind streams, and coronal mass ejections, because these in turn produce geophysical disturbances that disrupt Department of Defense satellite systems and aircraft operating in the space environment. With the advent of the Space Shuttle era, military planners are increasingly concerned with the extreme hazards to astronauts due to these bursts of deadly solar radiation, encountered especially in polar orbits during times of enhanced solar activity.

The Branch also has programs to improve our understanding of basic solar phenomena through space-based observations, image enhancement of ground-based observations which have been degraded by atmospheric turbulence, and observations of solar-like stars. Branch personnel are co-investigators on NASA's Spacelab 2, Sunlab, and Solar Optical Telescope missions. In addition, several experiments have been proposed for the Space Test Program of the Air Force Space Division. These missions will provide solar data in the x-ray and extreme ultraviolet spectral regions which are unavailable from the ground, but of fundamental importance to understanding solar activity. To improve ground-based observations, the Branch is developing both active optics (rubber mirror) technology and speckle interferometry (using post-facto computer reconstructions). Both of these imaging programs have now reached the payoff stage, and systems are being installed on ground-based telescopes. The Branch pursues a small program in solar-

stellar research, an important area in astronomy in which observations of solar-like stars are being analyzed to better understand the sun.

Solar Flare Forecasting: The approaches to the problem of forecasting flare activity are based on either physical processes or statistical relationships, depending on the time scales and types of data in question. Short-term prediction techniques rely upon observations of irreversible conditions which will lead to a flare within the following few minutes to approximately one hour. Within this time period, it is possible to detect either the pre-eruptive onset or the rapid energy build-up in current-carrying magnetic fields. Prior to the impulsive release of x-ray and particle emission, the actual flare onset is often visible in certain optical absorption features, microwave polarization changes, or weak soft x-ray signatures. The consensus of the Working Group on Short-Term Solar Predictions at the Meudon Solar-Terrestrial Predictions Conference (June, 1984) is that early recognition (0-30 min) of all major flares would be possible if optical, radio, x-ray and extreme ultraviolet data were available simultaneously. Studies of the pre-eruptive optical flare phenomena were sucessfully completed using data from the Air Weather Service and the Solar Optical Observing Network (SOON). The results are applicable to SOON observing sequences.

Research in current-carrying (sheared) magnetic fields has been carried out under contract, using both theoretical magnetohydrodynamic models and observations of vector magnetic fields in solar active regions. The association between flares and magnetic shear is well founded, although much additional research will be required to predict and observe the critical degree of shear which will lead to the actual flare instability, or "trigger." Analysis of photospheric magnetic field dynamics, inferred from sunspot tracers, has shown that transverse motion in the photosphere can effectively serve as a surrogate for the transverse field in detecting the locations and approximate magnitude of shear. This work has led to the formulation of observational parameters, applicable to SOON data analysis, which can be used until vector field data become available from space.

During 1984 the Solar Research Branch contracted NASA Marshall Space Flight Center to conduct an interagency workshop and design study for a Solar Activity Monitoring Satellite (SAMSAT). The motivation for SAMSAT is an Air Weather Service Statement of Operational Need regarding solar activity's effect on the space environment. The NASA study was guided by the Solar Research Branch and produced a final strawman instrument payload consisting of x-ray, extreme ultraviolet, visible corona, and vector magnetic field monitors; the study included detailed descriptions of costs, weight, power, orbits, and telemetry.

Solar Flare Processes: A major concern of recent flare research is the transport and distribution of flare energy with depth in the solar atmosphere. The problem is especially important in highly energetic, particle-emitting flares, for which known energy-transport mechanisms are proving to be inadequate to account for the radiative losses from the lower chromosphere. Important new information on the optical spectrum of such events was obtained at Sacramento Peak, leading to the conclusion that ionization and recombination of hydrogen atoms is the dominant emission process in many cases. Detailed measurements of the radiative losses as a function of time were compared with the associated hard x-ray bursts in several flares. The results show that if downward streams of high-energy electrons are producing the emission in the optical continuum, then the optical source must consist of an overdense region in the solar chromosphere. The latter conclusion may be of great importance in future studies of spatially resolved hard x-ray structures.

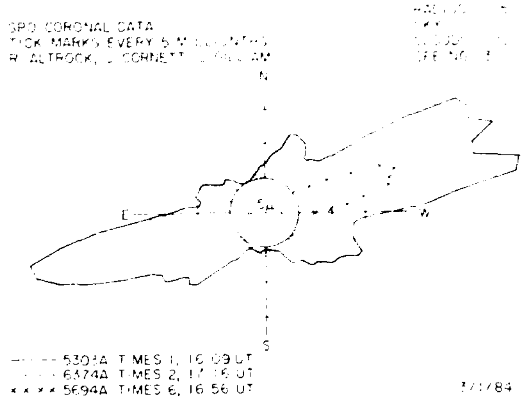
In a major collaborative effort between the Solar Research Branch and the Space

Particles Environment Branch, a catalog and statistical study of the highly energetic flares showing optical continuum was published (AFGL-TR-83-0257). Particular attention was devoted to determining the types of sunspot groups, types of magnetic configuration, and epoch within the solar cycle, from which such flares occur (see below). Seventy percent of these large flares were found to be associated with the production of energetic protons. These data, as well as the analysis of the optical spectra and radiative losses, were incorporated in NASA's Solar Maximum Mission Flare Workshop Series, in which several AFGL scientists were participants.

Future research, featuring coordinated observations between ground-based optical telescopes and NASA's Solar Optical Telescope and Pinhole/Occulter Facility, were planned and published in a NASA-funded report (MAX 91/The Active Sun). The report emphasizes campaigns of coordinated data-gathering efforts, organized around a number of scientific themes and objectives, including one directed toward the transport processes discussed above.

Coronal Images for Space Forecasting: The brightness of the solar corona on the east limb of the sun is a useful parameter for the prediction of geomagnetic disturbances detrimental to Air Force systems. Unusually bright areas herald the rotation onto the disk of an energetic active region that may emit high-energy radiation. Extremely dark areas are indicative of "coronal holes," low-temperature regions that are the sources of long-lived high-speed solar-wind streams. Such observations can only be made from high-altitude locations that are relatively free of atmospheric contamination. The Solar Research Branch conducts a program to obtain these observations at, and in cooperation with, the National Solar Observatory, Sacramento Peak.

At least once daily, scans of the solar corona are made in the light of FeXIV 5303Å with the 16 in. coronagraph telescope. This instrument produces an artificial eclipse, blocking out the bright disk of the sun and allowing only the million-times fainter light of the corona to enter the filter. The filter isolates light from thirteen-times ionized iron, which is formed only in the million-degree corona. Three circular scans are made around the limb to provide information about the height structure of the corona. A sample of the daily data is shown in the figure. These data are published monthly in *Solar Geophysical Data.*



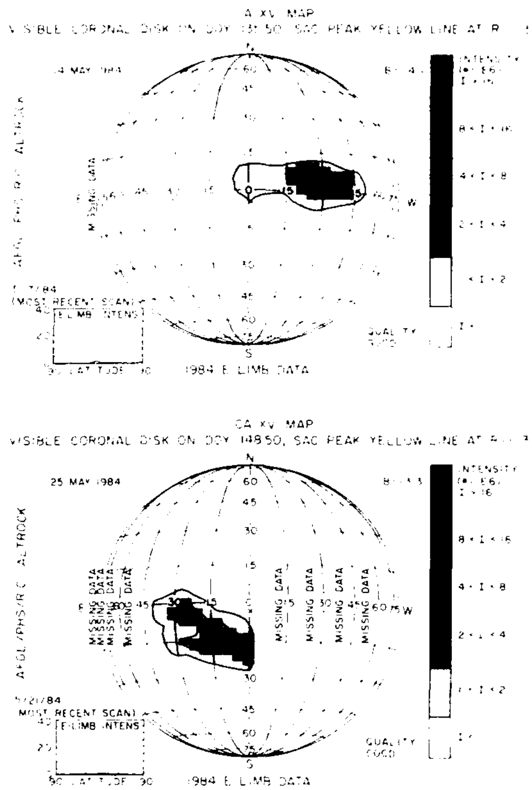
Polar Plots of Coronal Intensity in FeXIV 5303 A, FeX 6374 A, and CaXV 5694 A at 0.15 Radius Above the Solar Limb. (The intensity at the edge of the circle is zero. These lines are sensitive to average, cool, and hot coronal temperatures, respectively.)

A series of daily scans may be compiled into a "picture" of the sun's disk in coronal light, by utilizing the 27-day rotation period of the sun to rotate the limb scans onto the disk. Such maps are produced triweekly and telecopied to the space forecasting centers at Air Force Global Weather Central and the Air Force, NOAA, and the Space Environmental Support Center.

In January, 1984, we began the first synoptic observations of the sun in CaXV 5694Å with the Fisher/Smartt Photoelectric Coronal Photometer. These are the first observations ever made of this line with an instrument that subtracts the sky background. Earlier photographic and visual observations had shown emission only in very small knots over extremely active regions. Thus it was thought that

the high temperature required to produce CaXV (3-4 mK) occurred only rarely. However, we were fortunate that a rare situation obtained at the time of our first observations: there were two very active regions on the sun at a time in the solar cycle when activity should have been approaching zero. These regions showed strong emission in CaXV, implying the high probability of high-energy flares. Region A was situated roughly between latitudes 5° S and 25° N, depending on the apparition. Its centroid was observed at central meridian passage (CMP) on day of the year (DOY) 28, 56, 81, 108, and 134 of 1984, and it was not seen after that. Its total extent in longitude was approximately 50°. Region B covered the latitude range 10° N to 25° S at various times, and its centroid reached CMP on DOY 38, 121, 148, and 175 of 1984. It was not observed during the limb passages corresponding to CMP on DOY 65 or 92. Its total longitude extent was approximately 40°. Region B was not observed again after its west-limb passage on DOY 182. In addition, few further observations of CaXV were obtained during the remainder of the year. These regions are shown in the figure. We thus see that CaXV is ubiquitous to an extent never previously recognized. Temperatures of 3-4 mK are widespread over active regions in the low corona.

Consistent with classical concept that CaXV regions are major-flare producers, one of these regions produced a proton flare on February 16, 1984. The flare was not seen on the disk, and both regions were on the limb. Region B was on the West limb, which makes it a better candidate. Region B also produced the largest gamma-ray flare ever recorded on April 24, 1984.



Maps of the Solar Corona Produced by the Solar Research Branch in the Light of CaXV, Showing Two Major Active Regions Having High Flare Potential in 1984.

Solar-Cycle Variation of Corona: A series of daily coronal scans extending back to 1975 (and an isolated period in 1973-1974) have recently been compiled into a single-format computer tape. Programs are under way to study the solar-cycle variation of the corona. These will include comparisons with other data sets to determine the optimum parameters for space forecasting, as well as studies of solar rotation, active-region and coronal-hole evolution, and global solar properties.

Coronal Transients and Solar-Wind Disturbances: Recent observations from space have uncovered the occurrence of huge bubble-like disturbances in the outer solar corona, called "coronal transients." These transients have been observed to grow in size until they are as big as the sun itself, and further expansion certainly occurs out of the field of view. Studies have shown that they are frequently connected with mass ejections (e.g., eruptive prominences) and that the disturbances can travel out through the interplanetary medium and cause disturbances.

The Solar Research Branch has recently begun a program to search for these phenomena from the ground. As often as tele-

scope scheduling will allow, the AFGL/SPO daily corona-scan program is expanded to run continuously from sunrise to sunset. A series of pictures of the corona can be generated from the type of data shown in the preceding figure. Such a picture may be subtracted from subsequent pictures to display changes in coronal structure and brightness. Rapid change is indicative of the initiation of a coronal transient in the low corona.

He I 10830A Scans: The Solar Research Branch is supporting efforts to establish a facility to provide daily digital maps of the sun in He I 10830A. This atomic absorption line appears to be well-correlated with the location of coronal holes on the solar disk. While the Fe XIV line can only be seen at the solar limb, the 10830A line has the advantage of being "observable" on the sun's disk itself. It appears in the infrared and thus can be detected efficiently.

Origins of Solar Activity: The fundamental cause of the solar activity that impacts the earth's upper atmosphere and the near-earth space environment is the interaction between dynamical processes and magnetic fields in the sun. To understand solar activity and solar activity cycles, and thus provide better predictions of when activity will occur, the Solar Research Branch conducts research into the physical processes occurring in the solar atmosphere and in the atmospheres of solar-like stars. Progress was made in several areas towards understanding the transport of energy through the solar atmosphere and in understanding those processes that inhibit energy transport and lead to solar activity.

Variations in the Calcium K-line, as seen in integrated sunlight, have been observed from November, 1976, to the present. The K-line emission was shown to be a good indicator of the level of solar activity and the solar ultraviolet (UV) output. By monitoring the K-line it should be possible to predict the total solar ultraviolet emission. Knowledge of solar UV emissions is important to Air Force operations since they determine the height and charge density of the earth's ionosphere.

Work continued on the influence of magnetic fields on the transport of energy through the solar atmosphere. A direct correlation between magnetic flux and the amount of convective energy transport in the solar photosphere was established. An asymmetry of solar spectral lines formed in the photosphere results from the correlation between temperature excess and upward velocity in convective bubbles that are penetrating into the observable atmosphere. When magnetic fields are present, the line asymmetry is seen to change systematically with increasing magnetic flux. The change can be modeled by decreasing the amplitude of the convective motions and by increasing their height of penetration into the atmosphere. This implies that magnetic fields permit convection to deposit energy at higher atmospheric layers, but that the total energy being transported is decreased. The energy that is "bottled-up" may then become available for triggering activity. Further research is needed in this promising area.

A multiple diode array (MDA), consisting of several charge-coupled silicon detector arrays, each 320×512 pixels, was developed for observing several solar spectral lines simultaneously at high spatial and temporal rates. The MDA permits observations at both very short wavelengths (such as the Ca K-line at 3933A) and at very long wavelengths (such as the He 10830 line). This permits simultaneous observations of active regions at photospheric as well as upper chromospheric levels. This type of observation will help determine how velocities and magnetic fields interact in active regions. This should lead to a physical understanding of the magnetic twisting and shear which produce solar flares and mass ejections. To increase the data throughput, we are now interfacing the MDA with a 68000 based computer for on-line data reduction.

Another energy transport mechanism operating in the solar atmosphere is wave

propagation. The solar atmosphere permits gravity, acoustic, and magnetic waves, as well as various combinations of these waves to propagate. The effects of various wave modes on solar line profiles were computed to determine their detectability. The work shows that there is no fundamental limitation placed on our ability to detect propagating waves in the solar atmosphere by radiative transfer effects. Problems with detecting these modes of energy transport and storage are caused primarily by seeing effects in the earth's atmosphere. Use of these computations to interpret observations of waves propagating in the solar photosphere has shown that high-frequency acoustic waves are indeed a potential source of energy for atmospheric heating, especially in the low chromosphere.

A family of models describing the structure of small magnetic flux tubes and pores was obtained. These models allow the rate of spread with height of the flux tubes in both the photosphere and chromosphere to be computed. At sufficient heights above the photosphere adjacent flux tubes merge, producing more complex structures. Potential field models were shown to break down for magnetic fluxes greater than a few terrawebers. Thus, potential models are not capable of explaining sunspots.

Efforts by the Solar Research Branch to study the activity and variability of stars like the Sun continued through the 1983-84 period. Satellite measurements have demonstrated that the solar energy output undergoes fluctuations at the level of a few tenths of a percent, resulting from the passage of sunspots across the solar disk. A study of several young (10 percent solar age) solar-type stars in the Hyades cluster has demonstrated that most, if not all, of these stars display analogous variability, and at a more pronounced level than the Sun. These variations also offer a means for directly measuring the rotation periods of these young stars. Periods for twenty-one such stars have been determined in this study. Interestingly, the range in period for stars of a given age appears to be relatively small, which suggests that age is the primary factor governing rotation rate and, consequently, activity for stars like the Sun.

Most of the solar activity that disturbs Air Force systems and operations originates in localized areas on the solar surface called active regions. It is becoming increasingly evident that the Sun is not peculiar in this respect, and that the surface activity on other stars is also organized into active regions very similar to those observed on the Sun. On young stars, the fraction of the surface comprising active regions can be five to ten times larger than it is for the Sun. Thus, such stars provide a natural laboratory for studying solar/stellar activity under conditions and at extreme levels rarely encountered on the Sun itself, thus enabling theorists to separate more clearly the key factors governing solar activity.

High Resolution Imaging: The Solar Research Branch continues to support Air Force interest in high-resolution imaging techniques through both in-house programs and research contracts. The principal objectives of these efforts are (1) to obtain distortion-free images of small solar-surface features and (2) to develop the technology required to effectively use large, multiple-aperture telescopes to image spacecraft with enhanced resolution.

During the 1983-84 period, the solar imaging effort was focused on the development of (1) real-time active optics systems and (2) a post-facto solar speckle-imaging capability. Both efforts achieved considerable success.

A prototype active-optics system, incorporating a Hartmann-type wavefront sensor and a nineteen-segment active mirror for wavefront correction, has been fabricated, and has undergone several performance tests at the vacuum tower solar telescope at Sacramento Peak Observatory. The segmented approach avoids the crosstalk problems encountered with some continuous faceplate mirrors, offers higher bandwidth, and should facilitate expan-

sion to larger systems with more active elements. The technical performance and stability of the prototype have proven to be excellent. The full extent of the prototype's ability to improve the resolution of solar images remains to be explored. The tests to date have all occurred under relatively poor atmospheric conditions, which predictably handicapped the system's performance. However, even under these adverse conditions, the system was consistently able to improve the resolution of solar images by a factor of three or four above that of the uncorrected images.

Speckle imaging is a technique for recovering certain image information from the post-facto processing of multiple high-speed exposures of the target. However, it is difficult to produce a true image of the target using this technique. Instead, what one obtains is an image that has been scrambled in a special way, called an autocorrelation. A major roadblock to the development of speckle imaging techniques, especially for solar applications, has been the lack of ways to reliably unscramble autocorrelations. A CCD-based speckle camera, designed for optimal performance with bright, low-contrast targets such as solar images, has been fabricated and tested at solar telescopes at both Sacramento Peak and Kitt Peak. Software for processing and analyzing the specklegrams has been developed and installed at Sacramento Peak. Because the true appearance of the solar targets being observed is unknown, there are no "standard objects" available to calibrate the process. Therefore, two different algorithms for image recovery are being developed for comparison.

The problem of image recovery has been explored through analysis of very high resolution (0.1 arcsec) short exposure (4 msec) observations of solar granulation made at the Sacramento Peak vacuum tower telescope. Atmospheric degradation has been observed to take two distinct and separable forms: distortion and blurring. Distortion, the differential motion of the image, does not cause much local loss of high resolution information for short exposures. The amplitude of the distortion is typically 0.2 arcsec over a length scale of 1.5 arcsec. Blurring causes a reduction of high frequency contrast; it is not image preserving. It is observed to have a larger length scale than distortion, about 4 arcsec. Distortion is thought to be caused by turbulence near focus, and blurring by turbulence near the telescope aperture.

Distortion may be compensated by use of the "continuous correlation tracker" algorithm, a mathematical construct that determines the local image displacement that maximizes the cross correlation of the image with some reference such as an ongoing time average of many images. Since the resolution of the time averaged image is higher than the length scale for the distortion, this adequately determines its effect. The image is then remapped to give a distortion-free image. A sequence of such corrected images shows the solar structure in much better detail.

Blurring cannot be removed so easily, since it is an interference effect that is phase-destructive. In post-facto processing, a selection criterion is used to isolate those areas of frames which have the highest intrinsic quality. The criteria which have been found to work all use some measure of local contrast in the high-frequency filtered image. A technique called the "rms spatial filter" algorithm has been developed to give a spatially continuous measure of contrast that is used to select and weight portions of the image where the blurring may be reduced.

Speckle imaging is especially attractive as a technique for imaging high-altitude spacecraft, because it is not restricted to bright objects, as are active optics techniques. Significant strides have been made toward the goal of adapting the Multiple Mirror Telescope (MMT), which theoretically offers the highest resolution of any existing telescope, to image spacecraft at enhanced resolution. An optical system for coherently combining the beams from the telescope's six primary mirrors has been developed and tested.

The MMT has demonstrated sufficient mechanical and optical rigidity to retain coherence while tracking spacecraft. Coherence is essential if the combined image is to retain detail to the full theoretical resolution of the MMT - about 0.015 arcsec. Several successful resolution tests have been performed on astronomical objects and spacecraft of known size. The most serious handicap to further exploitation of this technique is the severely limited image-processing throughput presently available to the contractor: the processing duty cycle is only about 1 percent the data acquisition rate.

SPACE ENVIRONMENT

The Space Physics Division carries out and supports a wide-ranging program of research in the area of magnetospheric dynamics. In the 1983-1984 period, these activities have included: (1) analyses of in-situ space measurements of high latitude electrodynamic processes; (2) empirical, theoretical, laboratory and computer studies of substorm-related phenomena; (3) development of advanced instrumentation for upcoming Air Force missions in space.

High-Latitude Processes: Analyses of direct measurements of high-latitude processes were carried out using data from seven different satellites: S3-2, DMSP/F2, F4, F6, F7, P78-1 and HILAT. The S3-2 studies focused on electrical coupling between the high-latitude ionosphere and the distant magnetosphere. Instrumentation on the DMSP satellites varied from mission to mission. All the DMSP series carried spherical Langmuir probes and planar retarding potential analyzers (RPA) to measure the characteristics of cold plasma at topside altitudes. Precipitating electrons were measured in sixteen energy channels between 40 eV and 20 keV on F2 and F4. A new instrument capable of measuring fluxes of down-coming electrons and ions in twenty energy channels between 30 eV and 30 keV was flown on F6 and F7. This instrument, known as SSJ/4, will be flown on all scheduled DMSP flights through F14. Satellite DMSP/F7 also carried two new sensors, a body-mounted, three-axis fluxgate magnetometer and a dosimeter. Although results from F7 are preliminary, useful data are being acquired that will increase our understanding of (1) the field aligned currents that couple the magnetosphere to the high-latitude ionosphere and (2) the hard corpuscular radiation bombarding the ionosphere near the South Atlantic anomaly and during solar flare events.

The P78-1 is a fast-spinning polar-orbiting satellite whose orbit lies in the noon-midnight meridian. The Space Physics Division has contributed two electron spectrometers, identical to those on DMSP F2 and F4, to this satellite. The apertures of these detectors lie in the spin plane of the satellite looking 90° out of phase. Data from P78-1 have been used mostly to complement the magnetic local time coverage of DMSP F2 and F4 and to provide pitch-angle information about auroral zone, polar cap and cusp electrons.

The HILAT program is a joint AFGL, DNA and NRL effort to understand the creation, evolution and decay of naturally occurring ionospheric irregularities at high latitudes. Unlike irregularities at equatorial latitudes that are understood to be examples of a Rayleigh-Taylor instability, high-latitude irregularities are thought to be driven by gradient-drift ($\underline{E} \times \underline{B}$) and/or current convective instabilities. The polar-orbiting HILAT satellite was launched in the summer of 1983 to investigate the relative contributions of these two plasma instabilities to ionospheric irregularities and the degree to which structure in soft electron precipitation causes topside plasma irregularities. To address these questions the Space Physics Division of AFGL provided two complements of instruments. The first complement consists of three electron spectrometers that cover the range from 20 eV to 20 keV in sixteen energy bins. One detector looks toward local zenith, the second 40° from zenith and the third toward nadir. The second complement

consists of a spherical Langmuir probe, a retarding potential analyzer and a driftmeter. Although analyses of the results from HILAT are still preliminary, a higher than expected degree of correlation between soft precipitation and topside density irregularities is found in some local time sectors.

During the past two years, scientists within the Space Physics Division have maintained an active interest in the interactions of the polar cap with the solar wind and interplanetary magnetic field (IMF). The launch of the Dynamics Explorer (DE) satellites in July, 1981, brought new insights concerning the global dynamics of polar cap arcs and, for the first time, the chemical composition of precipitating energetic ions. Recognizing the complementarity of DE results with those of AFGL, the Division conducted a two day workshop in October, 1983, on polar-cap arc phenomena. Strong empirical evidence from DE suggested that during periods of northward IMF, the lobes of the magnetotail are bifurcated with closed tubes of magnetic flux. The important question from a theoretical point of view is how this could be accomplished. An important clue came from the MAGSAT satellite. Scientists at APL published measurements of the sun-earth component of magnetic deflections in the polar cap when IMF B_z was northward that showed a W-pattern. The shape was consistent with a region of sunward convections in the central polar cap. However, when MAGSAT was on the nightside of the magnetic dawn-dusk meridian, the magnetic deflection became highly irregular. This was reminiscent of the irregular electric fields always found in the winter polar cap and found 50 percent of the time in the summer polar cap S3-2 electric field measurements during periods of northward IMF. A quick review of S3-2 data showed that irregular electric fields in the summer polar cap only occurred on the nightside of the magnetic dawn-dusk meridian. Since this effect could not be explained by different ionospheric conductivities, it must result from a turbulent electric field in the distant magnetotail. The clear implication was that during northward IMF a turbulent reconnection of flux tubes was occurring in the neutral sheet. These tubes of flux merge under the influence of a dawn-to-dusk electric field that then rapidly converts them earthward. Because the dayside of the magnetosphere is already in pressure balance with the solar wind, the reconnected flux tubes are excluded from the dayside. Rather, closed flux tubes in the nightside plasma must move tailward to make way for the newly merged, earthward-moving flux tubes. In the ionosphere, these plasma-sheet flux tubes appear as convecting across the central polar cap in the sunward direction. When they reach the dayside cusp, they can merge with northward IMF field lines, becoming open and, thus, continuing the cycle.

Three other studies of more statistical natures were also brought to completion. The first examined the functional dependence of the polar cap potential as measured by the electric field detector on S3-2 with the solar wind IMF. These potentials ranged from 170 kV during a substorm to 12 kV during a period of northward IMF. The best correlations (– 0.8) were found with the interplanetary electric field $E = V_{sw} B_T \sin^2 \theta/2$, where V_{sw} is the solar wind speed, B_T is the tangential component of the IMF, and θ is the colatitude angle of the IMF in the solar-geomagnetic Y-Z plane. Since the polar cap potential is a direct measure of the coupling between the solar wind and the magnetosphere, this study will have long-range consequences for our ability to predict the portions of the high latitude region that are seriously affected by substorm activity. To make such predictive capability available, it is necessary to have regular access to information concerning the state of the solar wind IMF. Until the launch of the solar wind experimental satellite of the International Solar Terrestrial Program, this critical information cannot be obtained.

Two major studies of the morphology of polar-cap electron precipitation as measured by the SSJ/3 sensor on DMSP were completed in the 1983-1984 period. The first concerns the systematics of polar rain as measured by DMSP over a full year (September, 1977 - August, 1978) of continuous operations. Polar rain is a nearly uniform flux of soft electrons that precipitate poleward of the auroral oval on what are generally reported as open magnetic field lines. The DMSP data show that the integral flux of polar rain decreases by about a factor of 15 about an axis running pre-noon to pre-midnight. Access of polar rain to the northern (southern) hemisphere is favored during away (toward) sectors of the IMF. The second study examined the deviations of polar-cap electron fluxes above the level of polar rain. Such events are referred to as "polar showers" or "polar squalls" in the literature and are responsible for visual and subvisual polar cap arcs. Over 450 orbits of DMSP/F2 data were studied in the region of geomagnetic latitude >85°. The occurrence of such events was found to be almost exclusively controlled by the sign of the Z component of the IMF. If the Z component is northward polar, showers and squalls appear in both hemispheres. If it is directed southward, the precipitation is almost exclusively polar rain. The fluxes of polar shower electrons can range up to 10^{10} electrons/cm^2 sec ster., three orders of magnitude above polar rain. Because the peak energy of these electrons lies in the range between 50 eV and 300 eV, most of their energy is deposited at F- rather than E-region altitudes. Thus, they must be regarded as significant contributors to polar F- region density irregularities that cause scintillations of vhf and uhf radio signal transmissions.

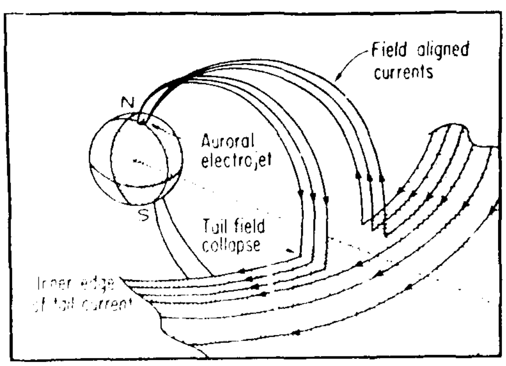
Although the HILAT analysis is still in its early stages, it was possible to carry out preliminary studies of F-region irregularities using mature DMSP and S3-2 data bases. In the first instance, soft electron precipitation and thermal plasma density measurements at 840 km were in spatial agreement with measured scintillations at Goose Bay. The second study of electric field and thermal plasma data near the Harang discontinuity showed an electric field that *did not* have the spectral shapes predicted by the non-linear gradient drift instability. However, the power spectral densities of the thermal plasmas did have the predicted k^{-2} forms. This, in conjunction with plasma-drift measurements from the Atmosphere Explorer satellite at 350 km which do not show great structure, suggests that the high-frequency portion of the electric-field spectrum does not map to the lower F-region. As a consequence, high-frequency potential drop structures must also exist which modulate the flux of precipitating electrons. This would provide a magnetospherically imposed modulation in the creation of topside plasma at a scale length of ~1 km. Preliminary analyses of HILAT measurements near the dayside cusp have revealed the predicted similarities in the field-aligned flux of downcoming electrons and variations in the perpendicular component of the electric field.

Substorm Phenomena: The principal source for ongoing data based substorm studies was the AFGL magnetometer network which operated continuously from late 1977 up to January 1, 1984. It provided a unique capability for studying magnetospheric processes through their manifestations in the surface magnetic field. It consisted of seven stations which spanned the contiguous United States, covering 60° of magnetic longitude and 15° magnetic latitude. Five were spaced across the northern states (Washington, South Dakota, Wisconsin, Minnesota, and Massachusetts) along a West-East chain at 55°N magnetic latitude, while two were located in southern states (California and Florida) at 40°N. All were identically instrumented with fluxgate and induction-coil magnetometers, which measured three components of the earth's magnetic field and its time derivative, respectively. The stations were unmanned and operated by microcomputers. Data were converted

to digital form and returned to AFGL in real time on a dedicated phone circuit. This also carried, in the opposite direction, a network-control signal to synchronize the measurements at all stations.

At each station, each component of the field was sampled once per second, and the time derivative was sampled five times per second. Synchronization was accurate to within a few milliseconds, so excellent time resolution was achieved. At AFGL, the data were processed and recorded on archive tapes. Operation from 1978 through 1983 resulted in a powerful, six-year data base which is immediately accessible for correlation with similar data developed by satellites and other ground-based efforts. During the past two years, this entire data base was transcribed into an acceptable format and transmitted to the World Data Center. It is thus available to the general Space Physics Community.

Studies based on magnetometer chain data fall into two classes, (1) identifying ground signatures of the substorm wedge and (2) comparing signatures of Pi-2 pulsations in space and on the ground. The figure illustrates the most widely held understanding of substorm initiation. Many satellite measurements show that, prior to substorm onset, the magnetotail becomes stressed by the addition of flux from the day to the night sides. The neutral sheet current intensifies and moves closer to the earth so that a satellite near geostationary orbit detects tail-like, rather than dipole-like, magnetic topologies. At substorm onset, the near-earth portion of the neutral sheet current becomes unstable, causing the current to close through the high-latitude ionosphere via field-aligned currents. Within the magnetotail, the central portion collapses near midnight, leading to a return to dipolar magnetic fields and intense particle injections at geostationary distance.

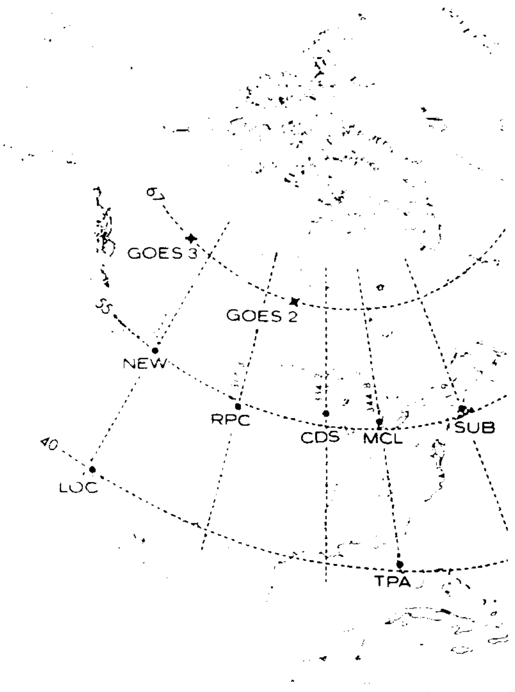


Initiation of Magnetospheric Substorm.

There are implications for the magnetic signatures observable by AFGL's longitudinally distributed chain of magnetometers at mid-latitude. Fringe magnetic fields from the field-aligned currents should have an eastward declination on the evening side of the wedge and a westward declination on the morning side. By examining the declination perturbation, AFGL scientists confirmed this prediction of the substorm wedge model and devised a practical method for identifying the longitude of the center of the wedge where the declination perturbation is zero.

The onset of substorm expansion is marked by a class of hydro-magnetic waves known as Pi-2 pulsations. These result from Alven-waves generated at the beginning of the interruptions of the neutral sheet current. They convey information throughout the magnetosphere-ionosphere system that the current system has undergone a temporal change. Although the signatures of Pi-2 waves are very clear on the ground, they are not easily detected in space. A major study was completed in the past two years looking for identifiable Pi-2 signatures on the ground and on GOES-2 and GOES-3 satellites at geostationary distance. As shown in the figure, GOES-2 is located at the longitude of the AFGL chain but GOES-3 is just to the west of it.

A substorm on July 16, 1979, was detected by the AFGL chain with a clear Pi-2 signature. While GOES-2 clearly detected the disturbances, GOES-3 did not. The implication is that although Pi-2 waves are widely dispersed in longitude at ground level, they are narrowly confined in space. This result goes far in explaining the lack



Map of AFGL Magnetometer Chain and Path of GOES Satellites.

of many clear signatures of hydromagnetic waves in space. It raises questions as to why this should happen — a subject of ongoing research.

Westward Traveling Surges: A major effort was expended in the 1983-1984 period to come to a theoretical understanding of the dynamics of westward traveling surges (WTS). These are characteristic auroral displays that occur in the midnight sector during substorms. Indeed, the hardest spectra of precipitating auroral electrons occur inside WTS. Severe charging of DMSP satellites are also observed in these regions. Up to the present time only static, empirical models of surges were available.

A unified model was developed for the propagation of a westward traveling surge that explains the diversity in the observed surge characteristics. The new, time-dependent model starts with the empirical Inhester-Baumjohann model for the surge region, which implicitly includes both the Hall and Pedersen currents. Precipitating electrons at the conductivity gradient were found to modify the gradient, causing it to propagate as a wave front. The velocity of propagation is directly dependent on the ionization efficiency of the precipitating electrons and therefore increases dramatically when they become more energetic during substorm onsets. For example, the model predicts that when the incident electron energy changes from 1 keV to 10 keV the surge velocity should increase from 2 km/s to 34 km/s. The direction of the surge motion depends on the presence of polarization charges on the poleward surge boundary. This is related to the efficiency with which the poleward ionospheric currents are closed off into the magnetosphere by the field-aligned currents. Inclusion of the electron-ion recombination rate modifies the surge propagation velocity and leads to explicit expressions for the conductivity profile. Sufficient precipitation current is required to overcome electron-ion recombination in order for the surge to expand. When the precipitating current is less than this threshold, the WTS retreats. Therefore, the model describes the ionospheric response to both the expansion and recovery phases of the magnetic substorm.

Another effort to increase our understanding of substorm processes was by way of computer simulations. Two major methods were employed over the last two years. The first involves the extension of the Rice convection model to include the geomagnetic tail. Both two- and three-dimensional simulation capabilities are being developed. One very interesting result of the analysis is that plasma cannot convect adiabatically from the distant magnetotail (say, lunar distance, 60 R_E) into the near-earth plasma sheet. Simulations performed with the new tail model show that the particle pressure that builds up in this way cannot be contained by the earth's magnetic field. An equilibrium solution with adiabatic invariance requires that the north-south component of the magnetic field in the tail develop a minimum between 10 and 15 R_E. This is

the precise location in the magnetotail where the empirically derived substorm wedge model places the initial neutral-sheet current interruption.

The second computer simulation study was carried out using the cusp current system measured by the S3-2 satellite in conjunction with the code developed by Kamide and Matsushita. The interesting results of this analysis are (1) the model does not predict the existence of a convection throat as reported from AE plasma flow measurements near the cusp; (2) the model does clearly predict the extension of the westward electrojet into the evening sector, poleward of the auroral oval. This is typical of the Harang discontinuity during substorm intervals.

Scientific programs of the various national space programs have been largely exploratory in nature. Instrumentation packages are designed to answer specific questions about what is out there. Periiods of exploration are inevitably followed by periods in which what has been learned is applied toward practical goals. Very expensive satellites must be protected against dangers from occasionally severe environments. Tests are devised to determine whether we truly understand the physics underlying space processes. If the space environment is perturbed, does that environment respond in expected ways? Like all "natural" processes, space events are quite complex. To gain quantitative information about these processes, theoretical models are constructed and powerful modern computers are employed. To some extent results may also be simulated in laboratory experiments.

Active Experiments: The Space Plasmas and Fields Branch has thus carried out, or supported, a program whose primary tools were computer or laboratory simulations. This program is called "active experiments" and looks forward to the day when space scientists, like their laboratory counterparts, can calibrate man-induced disturbances of space environments. The computer and laboratory simulations are used to determine how substorm energy might be released and how charged particle beams can be used to generate waves in space plasmas.

Detailed investigations of the magnetic reconnection process in the magnetotail were performed using plasma simulation techniques. One very successful approach treated the protons as particles but the electrons as a magnetized fluid. Because of the asymmetry between electron and proton motions near the neutral sheet, previously unreported Hall currents were found to be generated. These Hall currents appear to play a significant role in the onset of the tearing mode instability, which is considered to be the primary mechanism that rapidly converts magnetic to particle energy. The tearing mode onset was also found to be sensitive to the presence of streaming plasma near the neutral sheet. A three-dimensional fluid simulation of the plasma treated forced reconnection in the magnetotail. As reconnection proceeds, a shock structure appears that causes local interruption of the crosstail current. Field-aligned currents consistent with observations are generated. Utilization of these simulation techniques with laboratory tests is expected to delineate the most sensitive parameters for the magnetotail stability.

Laboratory experiments were performed in a "neutral" sheet device at UCLA to test the effects of neutral-sheet current interruption on the large and small scale magnetic topologies. A "counter" current was introduced into a very localized portion of the neutral sheet. Very rapidly, the previously stable magnetic field became disrupted and collapsed. Particle detectors in the device recorded large fluxes of very energetic ions associated with the disruption. The results tend to confirm the substorm current interruption model. It is a viable candidate for the heating of charged particles during substorms via inductive electric fields.

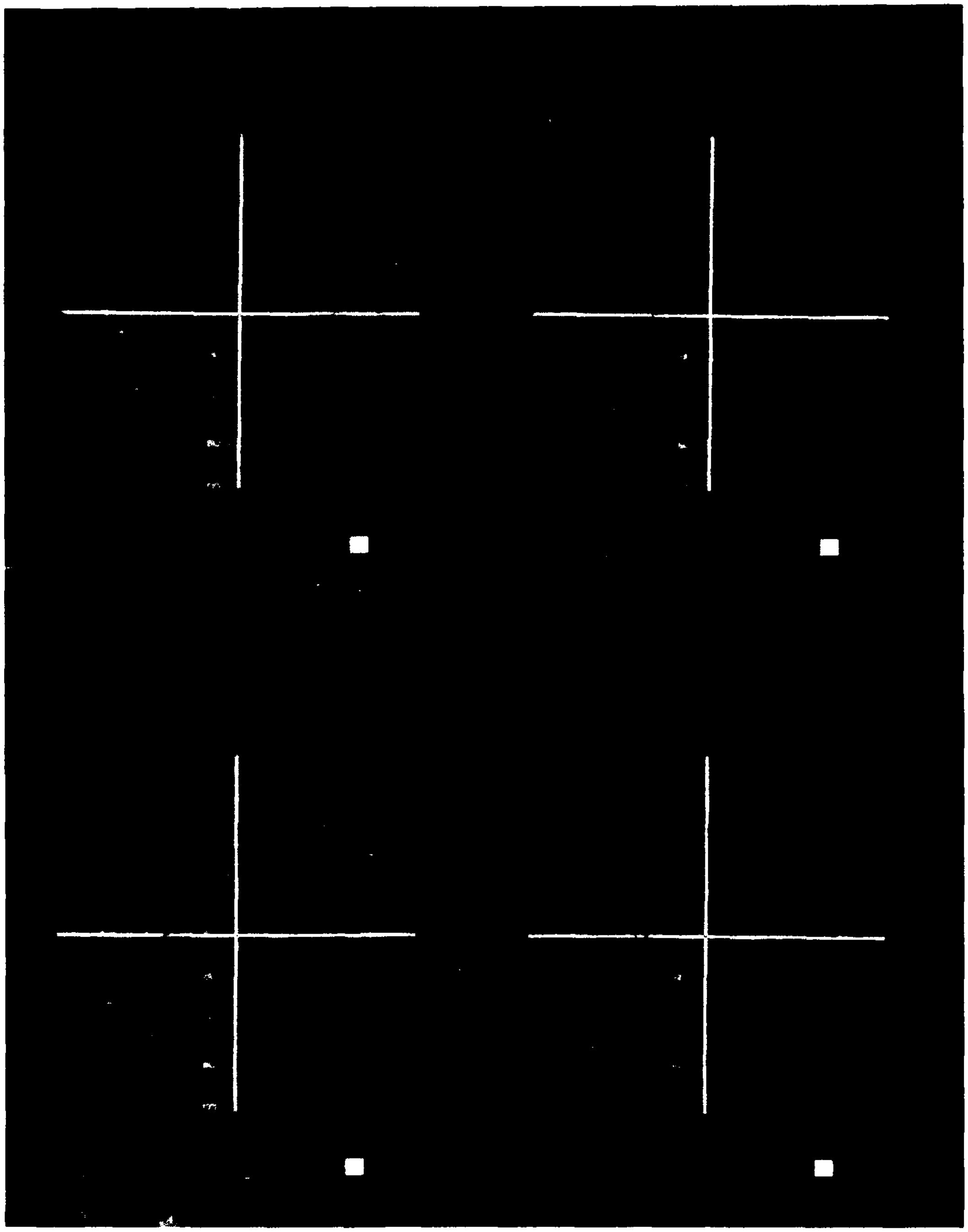
Finally, computer experiments were conducted at AFGL and at UCLA to understand the effects of charged particle beams on natural space plasmas. In the

case studied at UCLA, the beams were naturally occurring in the auroral zone. The beams studied at AFGL were artificially generated by an electron gun on the SCATHA satellite near geostationary altitude. The computer studies sought numerical solutions for the electromagnetic wave dispersion relations. It is expected that this code will become an invaluable tool for planning future active experiments in space, using charged particle beams as the source for space plasma perturbations.

SPACECRAFT ENVIRONMENTAL INTERACTIONS TECHNOLOGY

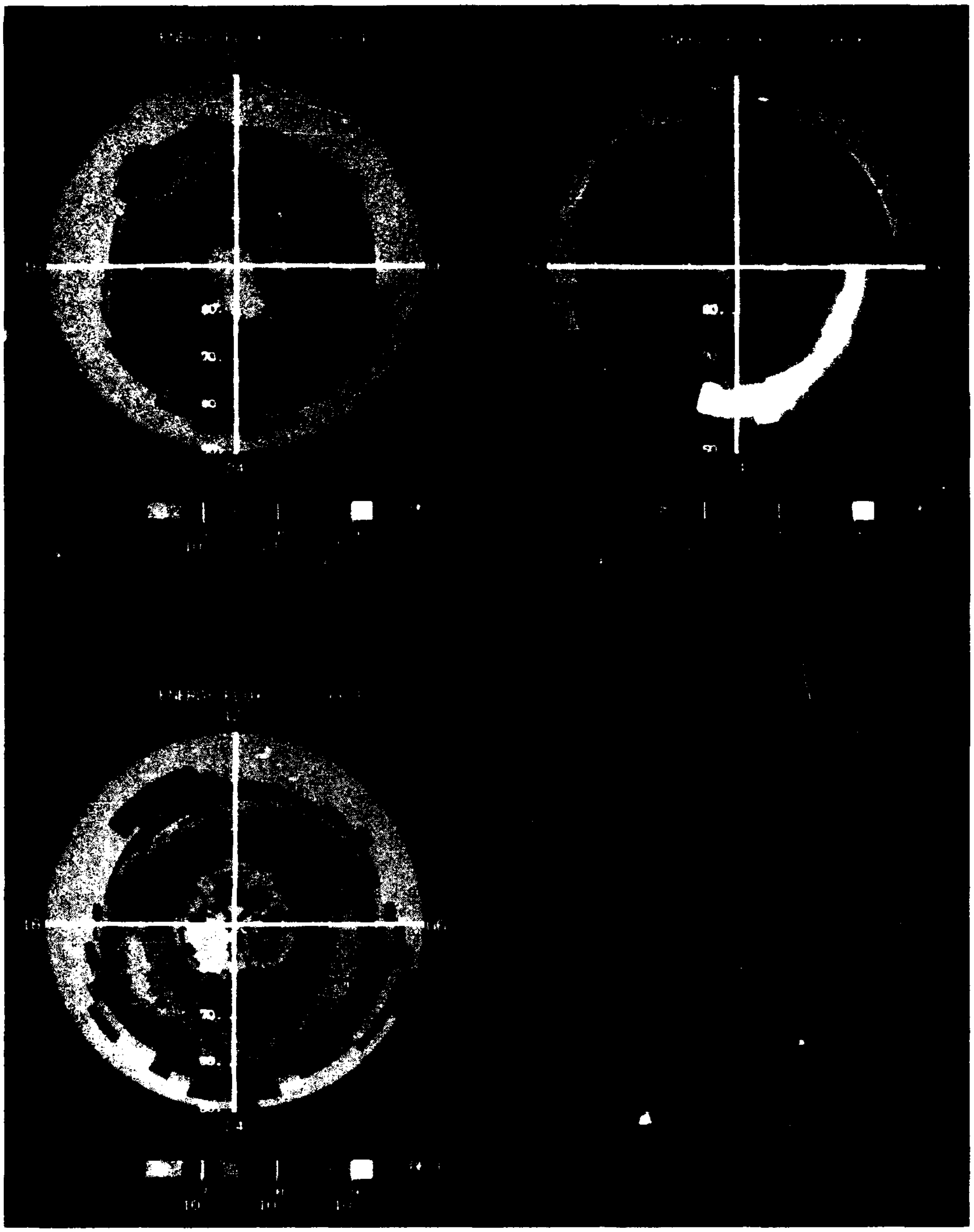
A Statistical Atlas of Auroral Electron Precipitation: A statistical study has been completed using data from the DMSP F2 and F4 satellites and STP P78-1 satellites to determine the average characteristics of auroral electron precipitation as a function of magnetic local time, mag : latitude and geomagnetic activity as measured by Kp. The characteristics were determined for each whole number value of Kp from 0 to 5 and for Kp $\geq$ 6–. At each level of Kp, the high latitude region was gridded, and the average electron spectrum in the energy range from 50 eV to 20 keV was determined in each grid element. The results show that the high-latitude precipitation region separates into two parts based on the electron average energy. There is a region of relatively hot electrons ($E_{AVE} \geq 600$ eV). In this region, the electron average energies are highest on the morningside of the oval. There are two average energy maxima at each Kp level: one post-midnight and the other pre-noon. The hot electron region is generally not continuous in Magnetic Local Time (MLT), but shows a gap between 1200 and 1800 MLT. The hotter electrons carry most of the energy flux into the oval. In the figure, the energy flux on the nightside shows an increase with Kp, while the level at noon increases with Kp when Kp is small, but decreases at higher Kp. The average energy of the hot electrons increases from Kp = 0 to Kp = 3, but is constant for higher Kp, approximately. In the second region, average energies are low ($E_{AVE} < 600$ eV). This region extends from the poleward edge of the hot electron region to the pole. The precipitating electrons in this region carry the majority of the number flux at high latitudes. The largest number fluxes are found on the dayside. The highest fluxes are confined to a crescent-shaped region centered slightly pre-noon and extending in MLT over most of dayside and, in some cases, into the the nightside. There is a pre-noon maximum in the number flux that shows little variability in MLT or in intensity with Kp. The average energy shows a minimum typically between 1100–1200 MLT located towards the poleward edge of the crescent-shaped region of highest integral number flux. The cusp is the region near the average energy minimum, and the cleft is the crescent-shaped region.

Spacecraft Charging in Low Altitude Auroral Region: Direct measurements of severe spacecraft charging in the auroral ionosphere have been made from DMSP. Due t the limitations of methods commonly used to detect particles and plasmas, few examples of spacecraft charging in the ionosphere beyond a few volts appear in the literature. This impasse has been overcome with the launch of the DMSP F6 satellite. It was equipped with up-looking detectors to measure twenty point spectra, once per second, of precipitating ions and electrons with energies between 30 eV and 30 keV. A wide geometric factor of the ion detector allows the application of a technique regularly used to identify the degree of charging for satellites at geostationary orbit. The Liouville Theorem was used to show that a spacecraft charged to approximately –100 V will not measure positive ions in energy channels < 100 eV. Because of the acceleration of cold ionospheric ions by the spacecraft potential, a large count rate should be seen in an energy channel centered near 100 V. A preliminary search of DMSP measurements shows that such



a. Kp = 0 – Kp - 3

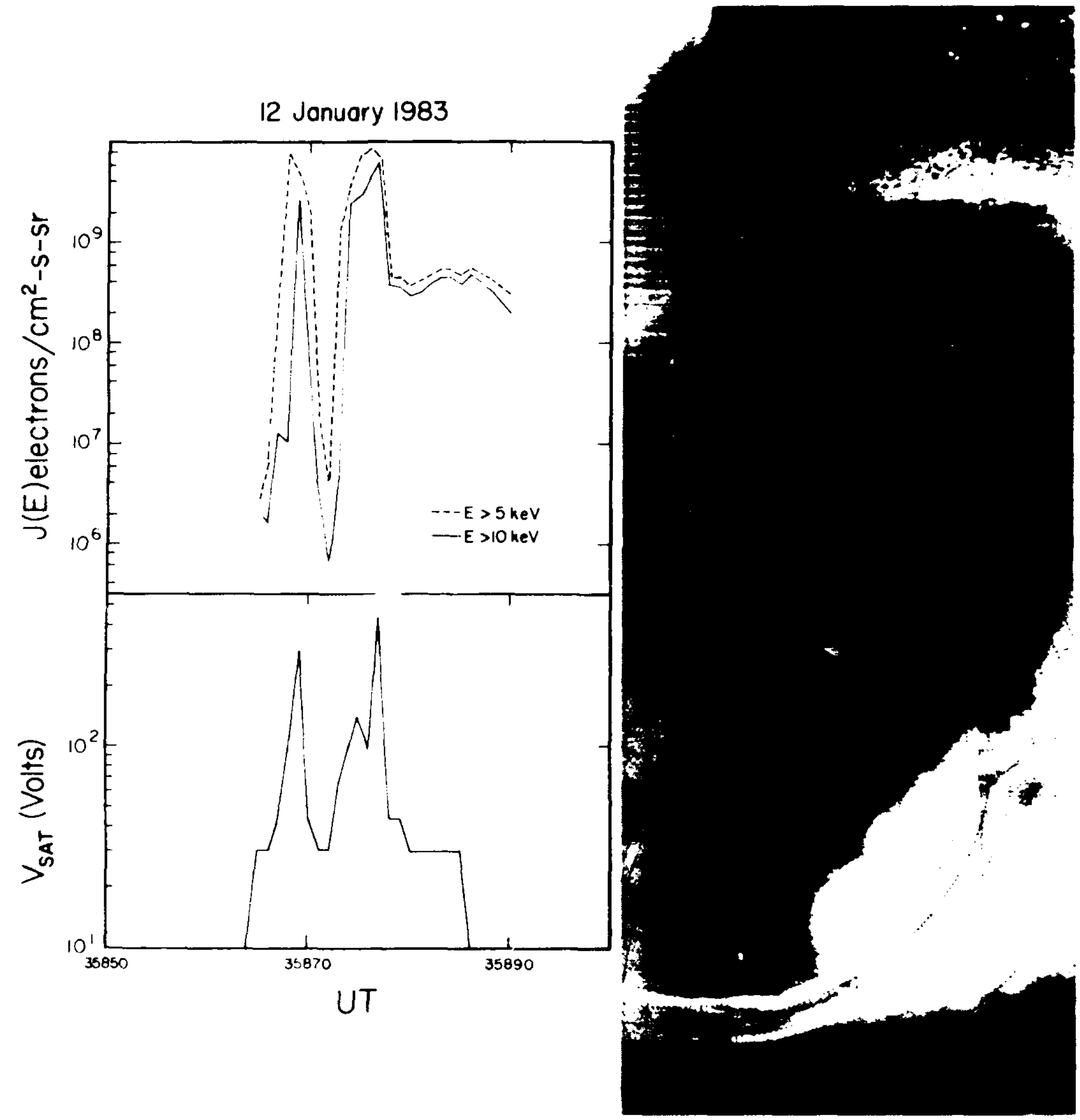
Polar Spectrograms of Average Integral Number Flux of Precipitating Electrons in a Magnetic Local Time-Corrected Geomagnetic Latitude Coordinate System for Seven Different Levels of Activity as Measured by Kp. (The colors are assigned on a logarithmic scale with four equal logarithmic divisions in each decade. The units are in el/cm^{2}s sr.)



b Kp 4 Kp 6

charging peaks frequently appear in the vicinity of intense "inverted-V" precipitation events.

Regions of intense keV electron precipitation, such as inverted-V structures, are sometimes co-located with ionospheric plasma depletion regions in the high-latitude polar ionosphere. When DMSP satellites enter these regions at about 800 km, ion signatures of high spacecraft-to-ambient plasma potential differences (several hundred volts negative) are fre-

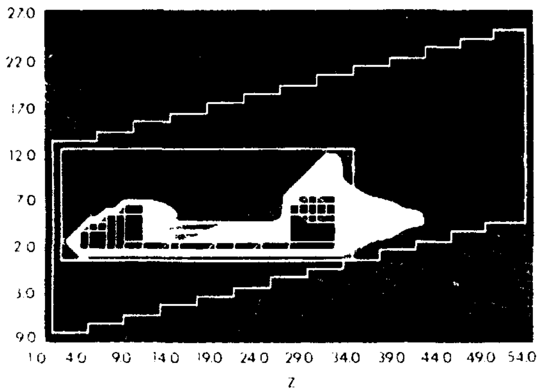


Low-Altitude Spacecraft Charging.

quently observed in the new ion detectors. A systematic survey of charging events and the environment in which they occur has been completed using the DMSP F6 and F7 precipitating ion and electron detectors, the SSIE thermal plasma probes, and the SSM (F7 only) vector magnetometer.

An example that closely approximates a "worst case" charging environment is seen in the figure. In this case, when the satellite intersected the aurora, seen in the right half of the figure, the peak electron fluxes simultaneously occurred in energies greater than 10 keV and charging peaks were observed in ion energy channels up to 440 eV. The fact that the spacecraft was charged to –440 volts was verified using the DMSP thermal plasma probe. It appears likely that dielectric surfaces in the wake side of the vehicle could charge to many times this number.

Space Shuttle Charging Code: DMSP data have shown that the charged particle

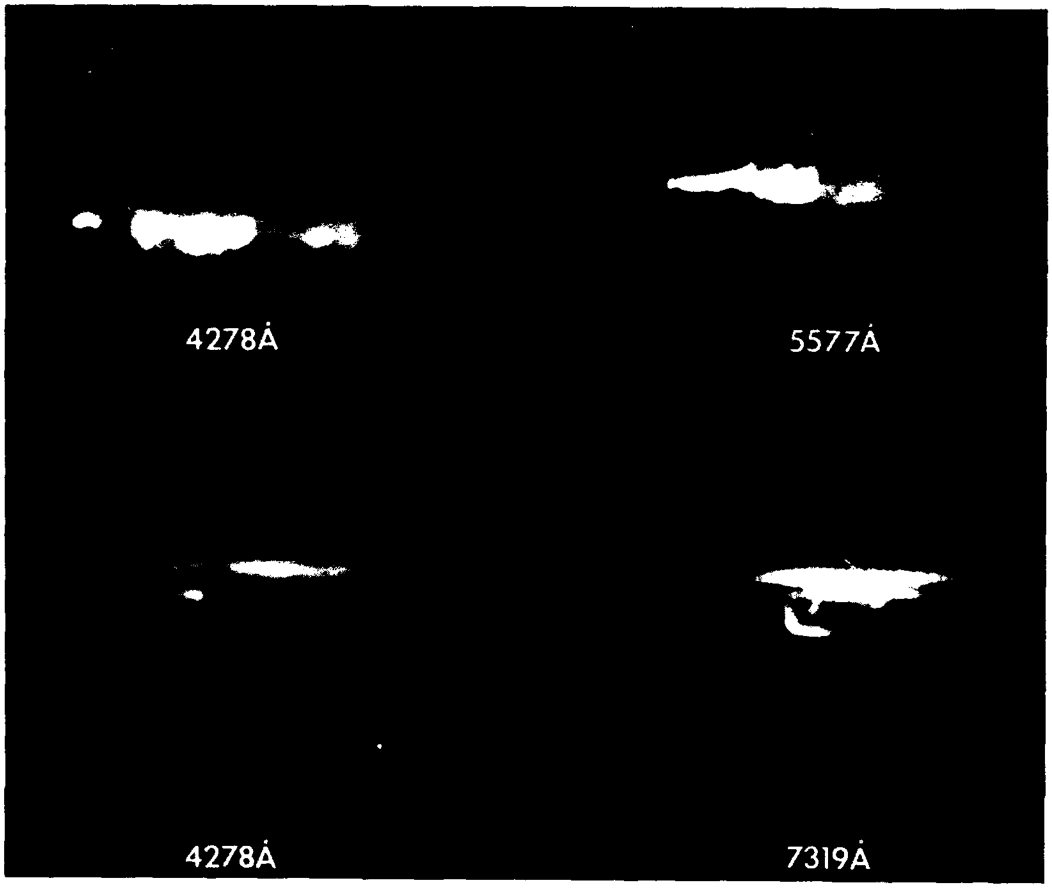


Shuttle Potential Distribution.

environment in low altitude polar orbit can be of sufficient intensity to cause spacecraft charging. To further the quantitative understanding of such effects, the POLAR (Potentials of a Large Object in the Auroral Region) computer code is being developed to simulate in three dimensions the electrical interaction of the Shuttle or any space vehicle with the polar ionospheric plasma. It models the physical processes of wake generation, ambient ion collection, effects of precipitating auroral electron fluxes, surface interactions including secondary electron generation and backscattering and vehicle charging (see the figure). The code follows these processes dynamically on a subsecond timescale so that the Shuttle's rapid passage through intense auroral arcs can be simulated. POLAR models the ambient plasma as isotropic Maxwellian electrons and ions (O^+, H^+), and allows for simultaneous precipitation of power-law, energetic Maxwellian and accelerated Gaussian distributions of electrons. Magnetic field effects are approximated by adding the appropriate $V \times B$ electric fields, and including pitch angle dependence in the precipitating electron populations.

The POLAR code computes charging in the ionosphere on each part of the Shuttle's surface. It does so by tracking ambient ram ions through the plasma sheath and wake surrounding the vehicle, and computing the incident auroral electron flux. The plasma sheath is relatively less effective in ion current collection for large vehicles, causing them to charge more than small vehicles. The equilibrium charging is computed by self-consistent solutions to Poissons's equation and particle tracking. A charging event on DMSP has been modeled with the neutral particle approximation for the ram ions. This model reproduced the observed potential and further predicted that the potentials in the wake region could be about 1 kV. These low-altitude charging events seen in DMSP data have confirmed the existence of the charging phenomenon, which is predicted to be more severe on large spacecraft like the Shuttle.

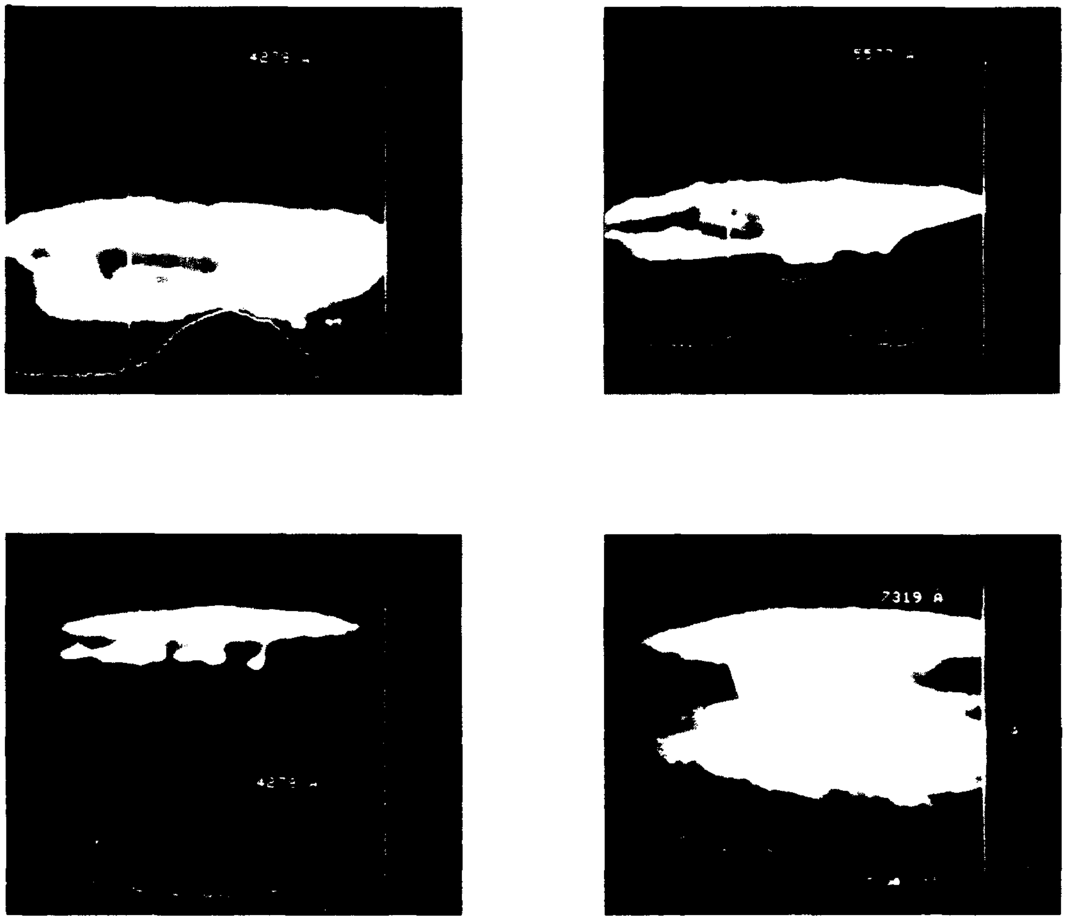
Auroral Photography from Shuttle: Some of the first photographs of the Earth's aurora, taken from the Space Shuttle (see the figure) were recorded by Mission Specialist Lt Cmdr David Leestma from an aft flight deck window of the Challenger during mission 41-G (STS-17). Auroras are produced through the collisional excitation of atmospheric gases by energetic particles which precipitate along geomagnetic field lines into the high-latitude ionosphere. These excited gases radiate at characteristic frequencies which can be detected using standard optical techniques. For the sequence of auroral images presented in the figure, a hand-held image-intensified camera with filters centered at 427.8 nm, 557.7 nm, 731.9 nm, and 427.8 nm (clock-wise from top left) recorded emissions from N_2^+, O_2,O^+, and N_2^+, respectively. The photographic data have been digitized and the images presented in an intensity-dependent color format in the next figure. The trace at the bottom of each scene indicates the height profile of detected radiation. The experiment was conducted near the beginning of a geomagnetic storm period on October 6, 1984, at the GMT indicated in the lower right of each photograph. During the 4 min over which these photographs were obtained, the Shuttle was traveling equatorward within the midnight sector as the camera viewed



Auroral Photography Experiment. Mission 41-G Challenger, October 6, 1984.

poleward at a discrete auroral form. The dynamic behavior of the aurora is evident from this time sequence of photographs. The conclusion drawn from these measurements is that the Shuttle is an excellent platform from which to perform auroral observations. Such studies are not, however, without difficulties in that the dynamic behavior of the aurora is not adequately represented by the techniques used here. Perhaps more importantly, the single filter system does not permit the simultaneous measurement of an auroral form at two distinct wavelengths which is useful in identifying mechanisms for the production and loss of excited atmospheric gases.

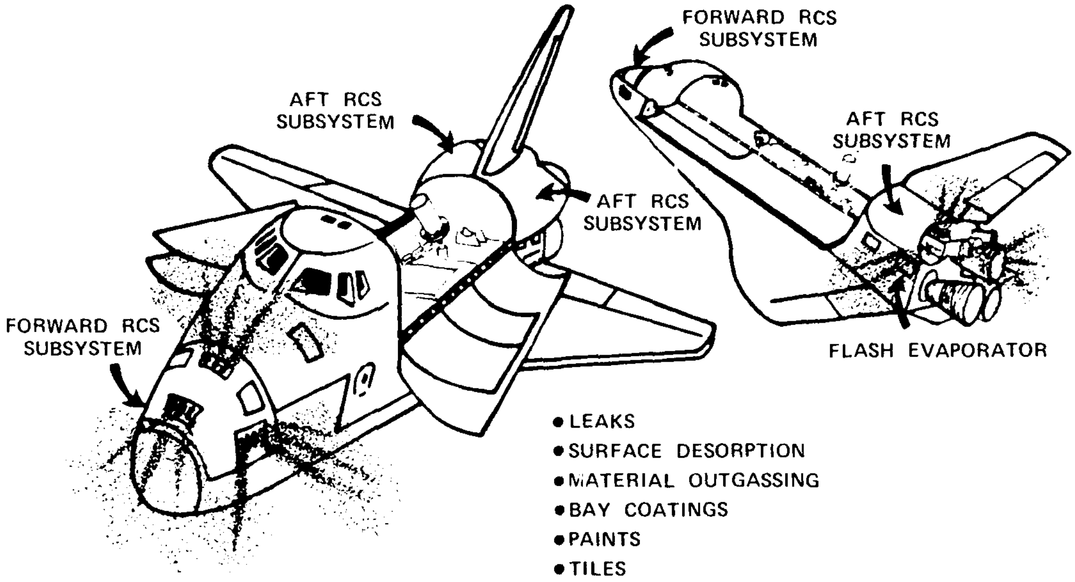
Spacecraft Contamination: Contamination as it applies to satellite systems is defined as the presence of foreign materials which adversely affects the performance of the system. Spacecraft systems can be degraded by contaminants throughout their lifetimes from the beginning of fabrication through on-orbit life. These contaminants are particles and molecular species originating from fabrication, operations, rocket exhausts, material dumps and construction materials. Vibration, acoustic agitation and thermal gradients cause migration of the contaminants from their source locations to other satellite surfaces. The effects of the contaminants are optical obscuration, scatter and absorption, changes in thermal radiative properties, and perhaps changes in surface electrical properties. The result is often a reduction in system



Digitized Image of Auroral Photography Experiment.

lifetime or a reduction in data quality. This is an unnecessary loss which can be prevented through development of appropriate contamination controls. The Shuttle represents a unique opportunity to examine many of the operational and system factors that are the source of contamination seen in the figure. In the newly initiated Contamination Program, measurements and model development efforts required to specify the Shuttle gaseous and particulate environments will be undertaken. Shuttle contamination will be measured with different payloads in the cargo bay, in polar and equatorial orbits and in different attitude orientations. The Shuttle contamination data base will be experimentally obtained and then generalized in models and specifications for application to military space systems.

Space Systems Environment Interactions Technology: This advanced development program began in 1983 to address the impact of the space environment on large space structures and systems to be designed and developed for the 1990's and beyond. The program capitalizes on space environment research results carried out at AFGL and other DoD and civilian research agencies to ensure that new knowledge of environmental sen-



Sources of Shuttle Contamination.

sitivities of emerging technologies is incorporated into the design and development of future space systems.

Over 100 different space environment interactions that can affect the design and operation of space systems have been identified. Proven mitigating techniques were also identified for some of these environmental effects. The results will be incorporated into updated design guidelines and military standards.

The Interactions Measurement Payload Program support is set up by an Engineering Science Working Group at Jet Propulsion Laboratory (JPL) to evaluate the technologies being developed for future systems and to identify and recommend engineering experiments for the first Interactions Measurement Payload for Shuttle (IMPS-1). The final selection of engineering experiments includes photovoltaic solar power arrays, space-based radar components, space-based laser optical materials, and a dielectric materials breakdown experiment. A complement of relevant environmental diagnostic sensors will also be incorporated into the IMPS payload. Through simultaneous measurements, it will be possible to specify the effects of the environment. Experiment design and fabrication have begun and a late 1987 flight is planned. The IMPS mission will use the Shuttle Pallet Satellite, which can be deployed from the Shuttle bay, so measurements can be made both within the environs of a large space structure, and in a more isolated free-flyer mode.

The Charge Control System utilizes results from the Spacecraft Charging at High Altitudes (SCATHA) program to develop an automatic charge-control system for geosynchronous satellites. SCATHA operations demonstrated that a satellite surface charge could be actively created and dissipated by using a plasma source. An Automatic Charge Control System being developed under contract by Hughes Research Laboratories will have three charge detection systems: (1) an electron and proton electrostatic analyzer, (2) a surface potential monitor system, and (3) a transient pulse monitor. A new, quick-start neutral plasma source is being developed that will essentially clamp the spacecraft to the background plasma and provide a mechanism to dissipate any differential charge build-up before a dis-

charge can occur. The initial breadboard design is scheduled for testing in April, 1985.

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WENXIU, L., SOJKA, J.J., and RAITT, W.J. (Utah St. Univ., Logan, UT)
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WITHBROE, G., and HABBAL, S.R. (Smithsonian Inst., Astrophys. Obs., Cambridge, MA)
Rapid Magnetic Energy Release, Its Possible Role in Coronal Heating and Solar Wind Acceleration
AFGL-TR-83-0086 (1 March 1983), ADA133170

WOLF, R.A. (Rice Univ., Houston, TX)
Study to Synthesize and Interpret Data from Several Satellites and Ground Magnetometer
AFGL-TR-83-0128 (3 May 1983), ADA132670

Launching a Tethersonde, a Device to Determine High Vertical Resolution Profiles of Winds, Temperature and Humidity and, hence, Refractive Atmospheric Structure. (The tethersonde, free-balloon radiosondes, and aircraft refractometers have been used to determine atmospheric refractive effects on line-of-sight digital radio networks for the Digital European Backbone (DEB) and on the TRC-170 Tactical Troposcatter Radio.)

V ATMOSPHERIC SCIENCES DIVISION

The Atmospheric Sciences Division investigates atmospheric effects on Air Force systems and operations. Present-day military operations are at least as dependent upon the weather as at any time in the past. While some Air Force operations will be less affected by weather elements, newer operations will involve more complex and sophisticated systems that are weather-dependent. Thus, the search for better methods of observing and predicting meteorological conditions continues to be a vital part of the geophysical research program of the Air Force.

During the period 1983-84, projects in the Atmospheric Sciences Division have included: research on cloud and precipitation physics and numerical modeling and simulation of cloud physics; atmospheric dynamic modeling and mesoscale prediction techniques; improved techniques for automatic satellite-imagery analysis, research on obtaining water-vapor profiles from satellites, and the use of satellites in providing weather data within uncontrolled or enemy-controlled areas and airspace; climatological techniques for the design and operation of Air Force systems and development of prediction techniques for toxic chemical spills; and automated Doppler weather radar analyses and coherent polarization-diversity radar techniques.

CLOUD PHYSICS

During the past two years, the Cloud Physics program has expanded modeling work while decreasing efforts in field pro-

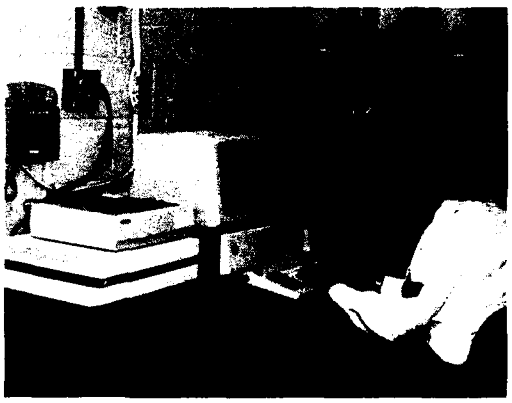
grams and instrumentation development. By incorporating knowledge gained in the field programs into the Cloud Microphysics Models, we will obtain a more complete understanding of such microphysical processes as growth of ice crystals and snowflakes, melting of the snow in the free atmosphere, and the growth and evaporation of rain and cloud drops. We have begun to apply the model results to Air Force areas of interest such as electromagnetic attenuation, aircraft icing, nuclear winter and scavenging of exhaust products deposited in the atmosphere by large rockets.

Cloud Microphysics Modeling: The purpose of this effort is to introduce more detailed microphysics into cloud models so as to provide more accurate simulated clouds for Air Force applications. Many Air Force weapon and communication systems are affected by processes such as microwave attenuation which occur within clouds and precipitation. Better understanding of the internal processes of clouds will enable engineers to design equipment which will operate more effectively in, and through, clouds and precipitation.

The Colorado State University 3-dimensional mesoscale cloud model, which includes parameterized microphysics, has been transferred from the CRAY computer at the National Center for Atmospheric Research (NCAR) to the CRAY computer at the Air Force Weapons Laboratory (AFWL) at Kirtland AFB, New Mexico. This model has been modified to include more sophisticated microphysics and has been applied to the problem of determining the mass loading of the atmosphere due to nuclear firestorms under different meteorological situations. For example, a warm, moist, unstable Denver sounding gave considerable loading of the stratosphere, where the particles would remain suspended for some time, while a dry standard atmosphere sounding showed no penetration of debris into the stratosphere. Confinement of nuclear debris to the troposphere would reduce the likelihood and severity of a nuclear winter.

This AFGL model is being run on five case studies provided by the World Meteorological Organization (WMO), part of the United Nations. The results will be compared with results from other researchers' models to find the weak and strong points of the various cloud microphysics models.

A detailed 1.5-dimension model with interactive microphysics was developed at AFGL about ten years ago for the study of warm cumulus clouds. This model has been reactivated and modified to include ice processes. The ice microphysics are being tested and verified against actual data using the 1.5-dimension model and are also being incorporated in the 3-dimension model.



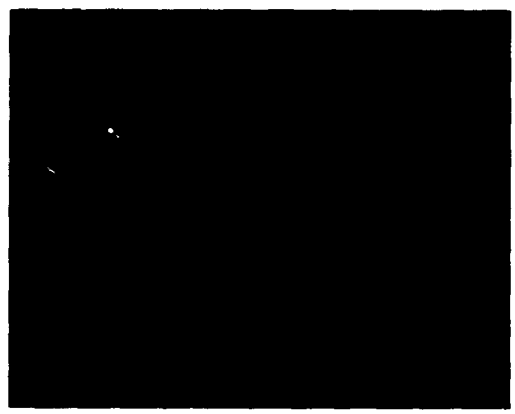
Computer Simulation of Clouds.

We performed a computer model study of depletion of aluminum oxide particles from the elevated exhaust ground cloud produced by a Titan rocket launched from Kennedy Space Center. The model incorporated deposition and impact collection, and included consideration of the particle size spectra. The computation results agreed with aircraft measurements taken inside the cloud, and showed that sedimentation plays the most important role in removal of the aluminum oxide during the first hour. A separate study considered the removal of debris from the elevated ground cloud by rain falling through the cloud from above.

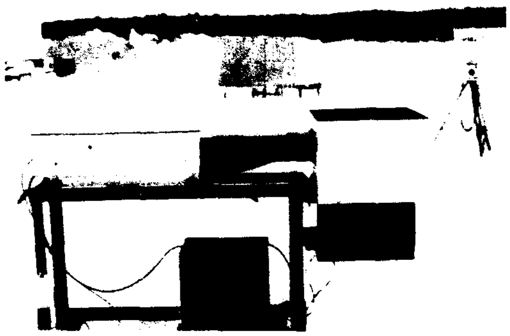
AFGL Snow Rate Meter employs an electronic balance to measure the weight of snowfall. (The data are used in attenuation studies, since snow attenuates electro-optical signals.)

Instrumentation Development: Five patent applications approved by the Air Force are being processed by the U.S. Patent Office. The Snow Rate Meter and the Rain Rate Meter use new electronic weighing balances to measure changes of 0.01 gram in 3 sec. Such small-scale time resolution has applications to narrow electronic beams being attenuated by rain and snow shafts in storms. Recent improvements have been made in the removal of wind pumping effects, in elimination of small drizzle coagulation on the collecting surfaces, in the automatic elimination of unusable data points, in achieving unattended operation of the Ra'n Rate Meter, and in operations of the Snow Rate Meter in adverse conditions. The Snow Characterization Meter has been improved by using a Geneva drive to stop the snowflakes in front of the TV camera, thereby enhancing the picture resolution and the snowflake definition. Backlighting was used in the Snow Fall Velocity Meter to provide more accurate data.

Two other instruments are being tested.



Recording Equipment for Snow Rate Meter.



AFGL Snow Velocity Meter uses a television camera (left) to look at snowflakes as they fall through a volume (right). Data are analyzed to obtain fall speeds.

The M-Meter is designed to measure from an airplane the mass of the liquid (or ice) water content in the atmosphere. This instrument is needed to investigate the melting layer where snow and rain coexist, and the data have applications to erosion of supersonic vehicles and to the attenuation of millimeter and microwave radiation. An automatic Snow Volume Meter has been designed and built to complement the other snow-measuring instruments.

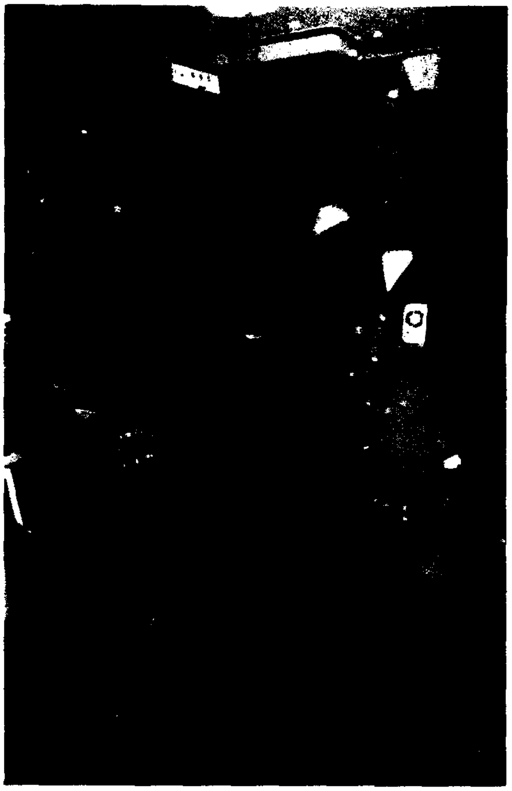
Comparisons of airborne data taken by a Rosemount Icing Detector, by a Johnson-William meter and by particle measuring systems equipment under supercooled icing conditions showed that the zero value of the J-W meter drifted with time. Otherwise, all three instruments provided reasonably accurate measurements of liquid water content within supercooled clouds, which causes aircraft icing.

Cirrus Clouds: The occurrence of cirrus particles in the upper troposphere is more common than previously reported. The presence of cirrus seems to be the rule in tropical regions, with clear conditions being the exception. Two different size distributions characterize ice particles in subvisible cirrus. The most common has a peak distribution in the 1 to 10 μ region with a rapid decrease of larger particles. The second type consists of ice crystals with diameters from 100 to 2000 μ which appear to have fallen from higher levels.

NASA and the Air Force have been investigating the possibility of using Laminar Flow Control (LFC) to decrease by 30 percent the drag on future large, long-haul transports. Limited experiments with the X-21 showed loss of LFC when flying in clouds. This was attributed to cirrus cloud particles blocking the small inlet holes on the wings. Recent studies, based on eight of our reports entitled "Cirrus Particle Distribution Study" (AFGL-TR-81-0316) and on the data gathered by NASA on their Global Atmospheric Sampling Program, indicate that on long routes the loss of LFC due to clouds is not large enough to make LFC impractical. In addition to heavy-lift, long-range transports, LFC has applications to subsonic reconnaissance and station-keeping aircraft.

Melting Layer Research: In most storm systems the precipitation begins as snow in the upper part of the storm. The snowflakes grow larger and fall until they reach the level where the atmospheric temperature rises to above freezing. This region where the snow melts, the melting layer, is of great interest since it usually has the highest water-content values in the storm, and it affects aircraft icing, erosion of supersonic vehicles and attenuation of electromagnetic signals. Research conducted in the University of Utah melting chamber is being utilized to improve the microphysics models mentioned above and in a separate study of turbulence within the melting layer.

Field Programs: The Cloud Physics Branch participated in the SNOW-ONE and SNOW-TWO joint-services battlefield exercises conducted at Fort Grayling, Michigan, which were sponsored by the U.S. Army Cold Regions Research and Engineering Laboratory. The instruments mentioned above were developed for, and used in, these exercises. The snowfall rates correlated well with the electromagnetic attenuation measured by other participants from the Army, Navy, Air Force and NATO. The extreme sensitivity of the Snow Rate Meter provided data showing evaporation of fallen snow after a



Television Monitoring of Snow Crystal Structure at Joint Services SNOW II-B Experiments at Camp Grayling, Michigan, January, 1984.

brief snow shower. Data exchanged by the participants are building a base for determination of attenuation caused by different types and amounts of snow.

In February and March of 1983 we flew our cloud-measuring instruments on the NASA Convair 990 aircraft to obtain particle type, size and ice/water content values while NASA scientists were taking 183 GHz radiometer measurements. The purpose of the experiment was to test the feasibility of using a satellite-borne 183 GHz radiometer to obtain world-wide vertical profiles of water vapor in the atmosphere. This type of information is critical in improving global weather forecasts. In a joint sortie with the British Meteorological Office's C-130 into a storm system over the Atlantic Ocean, an anomalous profile was obtained. We believe that the anomaly was due to a layer of ice crystals called "plates," which acted as mirrors to reflect radiation from other levels in the storm.

High temporal-resolution rain-rate data obtained in summer showers at AFGL are showing measured rain rates similar to those predicted from poorer resolution data.

Branch members provided consulting services to the Army and the Air Force on the erosion of ICBM nosecones due to cloud and precipitation systems. This included the rework of data taken by AFGL and others at the Kwajalein Missile Range. A review of the Reentry Measuring Program (REMP) as developed by AFGL and as currently being operated was presented to the Conference on Interactive Meteorological Processing which was sponsored by the Range Commanders Council.

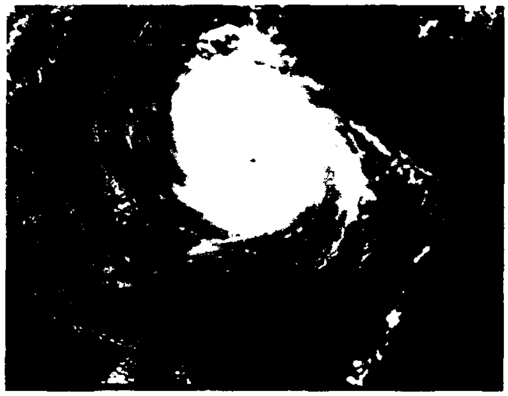
Extensive planning was conducted for two major field programs. The first is the Division's Weather Attenuation Program, which will take place in FY 86. The purpose of the program is to take in-situ and remote weather and attenuation measurements to enable us to learn how to predict electromagnetic attenuation due to rain and snow in the melting layer. The second program is the National STORM (Storm-scale Operational and Research Meteorology) Program. The first phase, STORM-Central, will be conducted in FY 88 in the Midwest and will focus on mesoscale convective systems. STORM-East will be located in New England in FY 90, to be followed by STORM-West on the West Coast of the United States in FY 93.

SATELLITE METEOROLOGY

Most of the meteorological satellites are either polar orbiting, providing global coverage twice a day for each satellite, or geostationary, providing coverage every half-hour over approximately a 60 deg latitudinal circle centered at the satellite subpoint. The data from the two types of satellites may be used for different purposes, but both yield information on cloud

and storm features indispensable for assessing the suitability or limitations of the weather for Air Force operations or systems, as shown in the figures. AFGL makes extensive use of a Man-computer Interactive Data Access System (McIDAS) because it has the capability of processing and displaying satellite imagery along with conventional surface and upper-air weather data in near real-time. Progress over the past two years has centered on (1) the development and testing of automated techniques for satellite imagery analysis, (2) the development of a differential inversion theory for the retrieval of atmospheric profiles, (3) an assessment of infrared and microwave regions for estimating water-vapor profiles from satellites, and (4) an assessment of using satellite data for improving the specification of moisture parameters in numerical weather prediction models. In addition, satellites have been considered as an important element in providing the required weather information within uncontrolled or enemy-controlled battle areas and airspace.

Automated Satellite Imagery Analysis: An automated cloud-analysis program known as the "R&D Nephanalysis (R&DNEPH)" has been implemented and

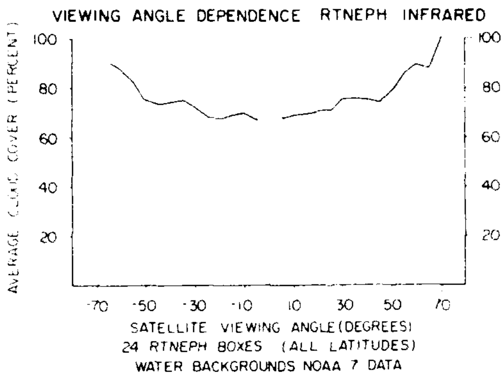


GOES Photograph of Hurricane Diana, September 11, 1984. (The center was located about 50 km south of Wilmington, North Carolina; sustained maximum winds were 135 mph.)

tested on the AFGL McIDAS. Successful cloud maps have been generated over most of the Northern Hemisphere for different seasons of the year. Infrared and visible imaging sensor data from the DoD Defense Meteorological Satellite Program (DMSP) spacecraft as well as NOAA polar-orbiting spacecraft are analyzed for cloud coverage and altitudes. The R&DNEPH was developed to allow AFGL improvements in cloud analysis to be made compatible with, and to be evaluated in, the cloud analysis programs at the AF Global Weather Central (AFGWC). Cloud analysis and forecasting are the highest priority research requirements of the Air Weather Service (AWS).

Satellite Photograph of Sea Surface Temperature Obtained on March 31, 1974, in the Gulf of Mexico. (Dark areas are warmest. A cold spiral ring may be seen in the upper left quarter of the photograph.)

The AWS has identified a number of potential improvements in GWC cloud analysis which have been studied using the R&DNEPH. The benefits of a finer mesh size for cloud analysis have been examined, and a finer mesh has been found to produce a slightly higher incidence of clear or overcast cloud-cover estimates. In a separate study, the automated analysis of weather satellite data has been shown to estimate higher cloud cover when clouds are viewed at oblique angles (see the figure). A major cause of viewing-angle bias appears to be inadequate corrections for atmospheric transmission in



Viewing Angle Bias.

automated analysis of infrared data. Some clear areas may be interpreted as cloudy, since the cloud-free temperatures measured by the satellites are colder than the inadequately corrected surface temperatures which are used as a reference. When clouds are scattered or broken over an area, the cloud cover usually appears higher from oblique angles because of geometric effects. The satellites will sense the sides of clouds, as well as their tops, so that clear areas appear to shrink or disappear at the oblique angles. This aspect of viewing-angle bias in satellite estimates of cloud cover is under study with cloud photography taken by the crew of the Shuttle mission STS-14. A number of suitable areas were identified by the astronauts, and each area was photographed at many viewing angles during a single STS overflight. Photogrammetric analysis of these data are in progress.

The interactive capabilities of the McIDAS allow different versions of automated cloud analysis to be displayed on a TV screen and readily compared with the input satellite data, or supporting maps of surface temperature, terrain heights, satellite times and viewing angles. Limitations and causes of poor cloud analysis are readily identified using this system. A major upgrade of the McIDAS was started in 1984 and will continue for the next two years.

The establishment of the R&DNEPH allows the development and testing of many possible approaches to improved cloud analysis. The DMSP microwave imager (SSM/I; earliest flight expected in 1985) is expected to improve the cloud analysis by identifying precipitating clouds and troublesome backgrounds such as snow cover or sea ice. The preflight software can be improved, and the benefits of improved cloud analysis can be assessed using the R&DNEPH. In 1984, the capability to process and display SSM/I data was developed. In addition to new sensors like the microwave imager, there is an abundance of satellite data which are not used in operational cloud analysis because of a lack of hardware, software or automated cloud analysis at AFGWC. These sources include fine-resolution DMSP imagery data, GOES imagery data, and the multispectral infrared imagery from NOAA polar-orbiting satellites. The latter data are particularly suited to the detection of low clouds or fogs at night, a difficult task, since these clouds may have the same temperature as nearly clear regions. A model to (1) simulate the NOAA multispectral radiances at 3.8, 10.5, and 11.5 μm, (2) detect clouds or clear areas, and (3) estimate cloud altitudes and coverage was developed. The radiance at 3.8 μm was found to be very useful for detecting low clouds at night, since the 3.8 μm emissivity of water clouds is usually low enough to distinguish the clouds from their backgrounds of higher emissivities.

Theory of Differential Inversion: Infrared and Microwave Water Vapor Profilers: A "Forward Problem" analysis of data from the three infrared water vapor channels and one window channel on the GOES system has been performed. (The "Forward Problem" is the attempt to match the observed or measured radiances with those expected from classical theoretical computations which are based on atmospheric parameters measured by radiosondes and which are considered to be representative of the conditions existing at the time and place of the satellite observation.) In a previous study, a discrepancy was found in the DMSP 15 to 30μm rota-

tional water-vapor continuum—namely, the calculated radiances exceeded the measured radiances by about 5 percent. With the launch of the Visible Infrared Spin Scan Radiometer (VISSR) Atmospheric Sounder (VAS) in geostationary orbit, it appeared that this VAS data could provide some insight into the Forward Problem discrepancies. The first VAS instrument was launched in September, 1980, on board NOAA's Geostationary Operational Satellite (GOES-4). Since then, two other VAS instruments were launched on-board GOES-5 and GOES-6.

Results of this analysis indicate that the Forward Problem discrepancy has not been resolved in the infrared region for water vapor measurements. Systematic discrepancies continue to appear in the comparison of the VAS water vapor radiances. In one of the window VAS channels, the discrepancies may be positive or negative depending on the time period considered. The use of the correct surface skin temperature is extremely important in the calculation and is definitely affected by the diurnal cycle. Large positive discrepancies are found around local noon where the radiosonde observation (RAOB) surface temperatures are used in the calculation. However, the percent deviations between the measured and calculated radiances may be greatly improved by estimating the surface skin temperatures using an additional window channel.

Systematic negative discrepancies are found in a comparison of one of the water vapor VAS channels. This result, that is, the calculated exceeds the measured VAS water vapor radiances, is in agreement with previous studies. However, in the case of another VAS channel, systematic positive discrepancies are found. This result was quite unexpected and may be due to a variety of causes. Some of these are (1) modeling the moisture content in the upper atmosphere climatologically, (2) inaccurate radiosonde water-vapor reports in the upper atmosphere, and (3) the absolute calibration for this particular VAS channel. Thus, doubts continue to exist in the Forward Problem discrepancy. At some radiosonde sites, the comparison results are excellent; others are marginal; and in a few the comparison results are totally inadequate. It may not be as easy as one would expect to compare the measured with the calculated radiances because of spatial and temporal moisture variations caused by the dynamical interactions of the upper atmosphere.

In a separate investigation of the DMSP temperature sounder operating in the microwave region of 50 to 60 GHz (SSM/T), no Forward Problem discrepancy was found. This result suggests that the problem with the infrared sounders lies either in the characteristics of the infrared instruments or in not being able to specify the atmospheric conditions precisely enough when making radiance comparisons. Since the microwave region is not sensitive to clouds with small water contents, some of the problems encountered with infrared sounders may not be present with the microwave sounders.

AFGL is continuing its investigation into inferring atmospheric water vapor profiles from passive measurements of microwave radiances in the 183 GHz (λ = 1.6 mm) spectral region. This research is in support of the DMSP special sensor water-vapor sounder. The channels being investigated are about the 183.31 GHz water vapor absorption line: 183.31 ± 1, ± 3, ± 7 GHz, and two window channels at 150 GHz and 90 GHz. A sensitivity analysis has been completed which shows the effects of various liquid-water cloud types in this spectral region. Qualitatively, water clouds will affect the retrieval of water vapor profiles. A quantitative analysis is progressing to determine the effects of water clouds on the retrieval of water vapor profiles. Past research has shown that intense storms or clouds with large liquid-water contents will affect water vapor retrievals. More accurate modeling of rain effects on retrievals via multiple-scatter calculations will be undertaken.

Satellite Data and Numerical Weather Prediction: A comprehensive review of us-

ing moisture information in numerical weather prediction (NWP) models has been completed. One result of this review was that the more complete use of satellite data to provide more comprehensive initial states and boundary conditions promises greater understanding and better predictions of short-range weather changes.

The prediction of clouds by modern NWP models is not better than a forecast of persistence out to 48 hr. Improved moisture analyses are needed, and satellite observations of moisture variables are essential. Since satellite data are incomplete and asynchronous, four-dimensional assimilation methods must be used. Better statistics and initialization procedures for moisture variables are needed. Improved boundary-condition data sets are also needed. These data are available, or are potentially available, from satellite observations. High spatial resolution is vital when moisture is involved because it varies more on smaller scales than other meteorological variables. Benefits that are expected to follow from the improved use of satellite moisture data are (1) improved forecasts of intense storms, (2) better precipitation and cloud forecasts, (3) better initial and boundary conditions for mesoscale models, and (4) better long-range forecasts.

Satellite and Other Types of Weather Data Within Battle Areas: As defined by the Military Airlift Command's Statement of Need (MAC SON 508-78 for Pre-Strike Surveillance/Reconnaissance System or PRESSURS), the Air Force critically needs the ability to observe and collect weather data at points within uncontrolled or enemy-controlled battle areas and airspace. Data must be processed and transmitted for use in Tactical Air Force decision assistance at in-theater weather facilities. Weather is a major factor in determining the success or failure of tactical air missions. Timely weather data, plus a knowledge of its effect on Air Force systems, is vital to the battle director in making tactical decisions. To accomplish this, these data must be provided to the in-theater weather facilities in near real-time.

MAC SON 508-78 requires measurements of cloud areal coverage (and the altitude of tops and bases), wind, temperature, pressure, humidity, path transmission, and contrast transmission. AFGL has analyzed forty-one possible weather observation alternatives. Four sensor platforms were considered in these alternatives: unmanned air vehicles (UAV), weather satellites, dropsondes, and surface-implanted weather sensors. A priority list of the required measurements and a list of non-meteorological goals were furnished by the user. An assessment was made of the capability of each platform to meet the goals.

It was concluded that it is feasible to measure the weather parameters of greatest operational concern in tactical situations: the cloud parameters and visibility. Requirements for measurements at a maximum range of 200 km beyond the Forward Line of our Troops and for data availability within 15 min of measurement are primary cost drivers. Other important requirements are those for physical and communications survivability in a hostile environment.

The weather observation concept with the greatest potential of meeting TAC/TAF requirements, both meteorological and non-meteorological, was selected. It involves the use of an enhanced satellite system complemented by UAV's. Weather satellite enhancements include improved ground-data processing, distribution, and display using tactical vans now supporting TAC/TAF field operations. The UAV will provide weather observations that cannot be obtained from a satellite, while the satellite would continue to provide critical information which could be used to determine when UAV's are needed. Sensors to be employed on the UAV will be tested. A complete weather observation system will be integrated and tested on a PAVE TIGER UAV.

Tactical Decision Aid Development: Air Weather Service Geophysical Re-

quirement 9-73 (Forecasting Aids for Precision Guided Munitions) states a need for forecaster aids which will allow an estimate of maximum target detection and lock-on range based on known sensor target and environmental parameters. These aids, called Tactical Decision Aids (TDA), are being developed for use by battle staff planners and air crews to insure effective employment of precision guided munitions (using infrared, television, laser, and millimeter wave guidance systems) under battlefield conditions. Tactical Decision Aids were developed which can be used to predict the performance of 1.06 μm laser designator, television, and 8-12 μm infrared precision guided munitions and target acquisition systems under a wide variety of environmental conditions. The TDA's are based on models developed at AFGL, AFWAL, and AFATL. Priorities were established for environmental parameters which influence the laser, television, and infrared system performance. These parameters were separated into two categories: (1) routinely measured and forecasted and (2) nonstandard parameters. A consideration of forecast reliabilities and limitations led to the development of environmental models needed to eliminate the limitations and improve reliability. AFATL's Target to Background Contrast Models (for infrared) and AFWAL's research-grade TDA (which includes specific sensor modes and an atmospheric transmission model developed by AFGL) were used as the foundation for AFGL's operational TDA development.

Calculator versions of these TDA's were completed for laser, television, and infrared systems. They can be used by weather forecasters and decision makers in the field. The TDA has been successfully employed at a number of locations. It has also been used for test and operational support of infrared systems and for test support of an advanced laser designator system.

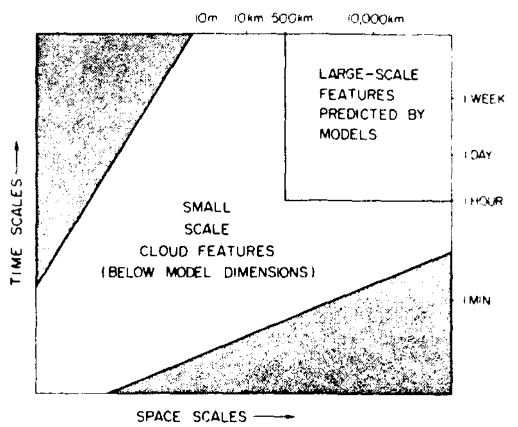
ATMOSPHERIC PREDICTION

Basic research studies in atmospheric prediction have concentrated on global and regional scale atmospheric modeling. Concurrently, exploratory development programs have become focused primarily on the development and evaluation of computer-compatible mesoscale techniques and models which will provide point and area forecasts of surface wind and sensible weather (clouds, visibility, precipitation) for time periods out to 12 hr. Techniques and models under development are expected to have the potential of operational application in the Air Weather Service (AWS) at either the Global Weather Central (AFGWC) or at the nearly 200 base weather stations which AWS mans around the world. Consideration is given to the capabilities and/or limitations of current and future systems in the formulation of models (techniques). Other studies examine the benefits that could accrue to operations if the system capabilities were expanded beyond present operational limits, particularly as regards additional data sources.

Atmospheric Dynamic Modeling: Much of the progress attained during the past two to three decades in weather forecasting accuracy can be attributed to advances in numerical simulation models of broad-scale weather circulation patterns. The accuracy of the numerical models depends on three factors: (1) the accuracy or completeness of the physical laws governing atmospheric interactions, (2) the accuracy with which the mathematical statements expressing the physical laws are carried out computationally, and (3) the adequacy of data bases used to initialize the models. The large-scale research program at AFGL has turned to the development of a research-grade spectral model of the global atmosphere. In recent years there has been a substantial shift from finite-difference methods to spectral numerical-simulation methods at both

operational forecasting facilities and international research centers. This has been due mainly to the advent of the so-called "transform" method, which makes spectral methods competitive in terms of computer time and memory requirements. The AFGL global spectral model (GSM) follows closely, therefore, the structure of many other multi-layer spectral models (i.e., horizontal variations represented by expansions in truncated series of spherical harmonics and vertical variations represented by values in discrete layers). The basic equation set includes the equations of motion in sigma coordinates, momentum (represented by absolute vorticity and divergence), continuity, hydrostatic and thermodynamic equations (the last two in forms suited to Arakawa vertical differencing).

Certain subgrid-scale physical processes must be accommodated within larger scale numerical simulation models through procedures known as parameterization. In establishing a baseline model at AFGL, we have adopted the global spectral model being implemented operationally at AFGWC as a point of departure. The parameterized physical processes in it fall into three broad categories:



Schematic Illustration of the Temporal and Spatial Scales of Atmospheric Phenomena. (Important cloud and moisture characteristics occur on scales much smaller than the resolution of global numerical models and must be accounted for by means of physical-statistical parameterization methods.)

boundary layer processes; moisture physics, including convective adjustment and large-scale saturation effects; and subgrid-scale diffusion.

Numerical simulation models require objectively analyzed fields of global meteorological data to operate on. Considerable attention has been paid to the development of multivariate optimum interpolation (OI) methods which focus particularly on the three-dimensional global moisture distribution. Methods to blend all direct and indirect sources of moisture observations (RAOB, aircraft, satellite and surface-based) are being tailored to the needs of the global cloud-forecasting model. Typically, these analyses result in imbalances between mass and motion fields which lead to unwanted gravity waves in the resulting simulation. These waves are suppressed or controlled in the model by effecting an initialization procedure referred to as the "non-linear normal mode method." This method provides conditions compatible with the numerical scheme of the model, generates realistic vertical motions and produces balanced flow over terrain.

The current computer system at AFGL (CYBER 750) constrains the resolution of the baseline research model to wavenumber 15 and 6 vertical layers (referred to as the "coarse resolution" version); while the CRAY-1 computer at AFWL permits expansion to at least wave-number 30 and 12 layers ("high resolution" version). A series of low and high resolution forecasts were generated for a January and July period of the First Global GARP Experiment (FGGE) to test the performance of the baseline version of the GSM. In general, increasing the resolution resulted in reduced forecast errors in the 24-96 hr range. By 96 hr, the low resolution model loses its skill in forecasting the height fields. The high resolution forecasts still have skill (compared to persistence) at 96 hr and probably retain some skill out to 6-7 days.

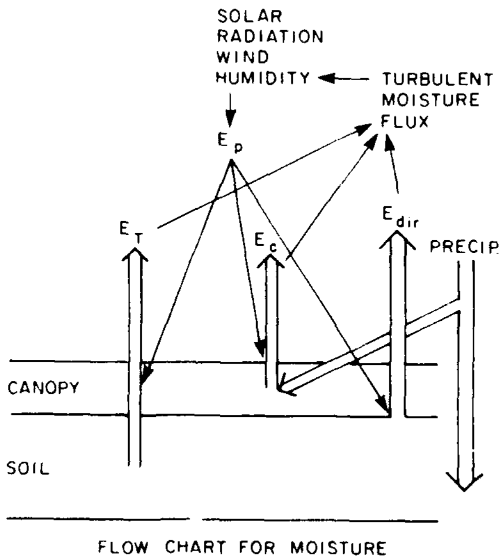
Moisture forecasts are the least skillful aspect of the GSM model, exhibiting only

minimal skill regardless of the model resolution. This problem can be attributed, in part, to the poor quality of the analyzed humidity fields, to the moisture physics parameterization schemes, and/or to the vertical advection technique for the model's moisture variable, specific humidity.

Sensitivity studies of GSM model performance vis-à-vis the representation of topography yielded the formulation of a smoothed topography interpolated to the model's Gaussian grid and spectrally truncated at the model's resolution. This form of topography provides consistency from the model's preprocessing stage to its postprocessing stage, where model forecasts are transformed back to pressure surfaces. Finally, an evaluation of the effect of the model's nonlinear normal-mode initialization procedure reveals that it contributes most to improved forecasts in the period up to 24 hr, after which the damping effects of the model's semi-implicit time-integration scheme and subgrid-scale diffusion are able, by themselves, to control undesirable gravity waves.

The vertical structure of the AFGL GSM is comprised of terrain-following sigma surfaces, while the process of creating OI-based global analyses of mass, motion and moisture variables is necessarily performed on pressure surfaces. In the process of initializing the numerical model and in the post-integration phase wherein model forecasts are used or evaluated, there are vertical interpolation steps which must be executed to transfer analyzed fields on pressure surfaces to model sigma surfaces and vice versa. In an error analysis of this aspect of the model process, the choice of the moisture variable used in the vertical interpolation phases was found to be crucial to preserving a reasonable moisture distribution for the model simulations. Because of the inherent differences in the vertical "linearity or lack of it" among the variables' specific humidity, dewpoint temperature and relative humidity, using specific humidity yields much larger positive moist biases in the middle troposphere than do the other variables. Since specific humidity is the preferred moisture variable for the model integration because of its physically conserving properties, we found that transforming it to logarithmic form prior to performing a vertical linear interpolation (in ln pressure) eliminates most of the earlier bias.

Planetary Boundary Layer Processes: For simplicity, most global circulation models neglect the influence of surface moisture flux over land because they are mainly concerned with the prediction of mass and motion fields and, perhaps, precipitation. In the quest for global models tailored for moisture and cloud forecasting purposes, surface moisture flux can have important influences on the diurnal development of the planetary boundary layer, related low cloud fields, and mass and motion patterns in general. Considerable research has been concentrated, therefore, on the development of models for stability-dependent potential evaporation (E_{dir}), for soil hydrology, for potential evaporation (E_p), for transpiration (E_t), and the canopy water budget (E_c) and for the atmospheric boundary layer. The figure depicts, schematically, these terms (models) and their interactions with the



Moisture Models and Their Interaction with the Turbulent Boundary Layer.

turbulent boundary layer. Sensitivity testing of these models running as an integrated entity have yielded reasonable behavior. Further testing to examine the interaction between the various model components for a variety of atmospheric conditions is underway, as are plans to incorporate the scheme into the AFGL GSM for sensitivity tests.

Infrared and Solar Radiation Effects: Another factor neglected in many global circulation models, but one that has greater importance when the model's purpose is moisture and cloud forecasts, is radiation effects. A broadband emissivity and absorptivity approach was used to develop a computationally reasonable parameterization model to account for the transfer of thermal infrared and solar radiation in clear and cloudy atmospheres. The emissivity for the individual absorption bands was derived either from band models (water vapor and ozone) or line-by-line data (carbon dioxide). High clouds in the atmosphere were treated as non-black and their emissivity, transmissivity and reflectivity were parameterized in terms of their vertical ice content. Solar radiation was accounted for by developing broad-band absorptivity for water vapor, carbon dioxide and ozone. Cloud reflection and transmission properties were parameterized in terms of liquid water content and solar zenith angle. These properties were then used to compute upward and downward radiative fluxes for clear and cloudy atmospheres having one or two layers. Sensitivity tests, conducted in part with the low resolution version of the AFGL GSM, have validated the accuracy and computational efficiency of the radiation parameterization schemes.

Regional NWP Models: The operational Air Forces require cloud forecasts on horizontal scales (50-100 km) that can only be obtained, computationally, through the use of limited area or regional NWP models. Because there has been substantial interest internationally in forecasting mass, motion and precipitation on these scales, there is ample evidence that regional models can indeed deliver useful and more detailed forecasts of these variables out to 48-60 hr. Here, again, the main USAF interest is for cloud and moisture forecasts, where little emphasis has been placed up to now. We undertook, starting in FY 84, a program to develop and validate regional NWP model(s) tailored to clouds and moisture forecasting, building on the improved parameterization schemes developed for the GSM.

Mesoscale Prediction Techniques: Improvements in mesoscale (or short-range) weather prediction can be tied to a more complete description of the atmosphere at observation time and changes in its recent past. The extent of spatial and temporal detail incorporated into this capability, generally referred to as "nowcasting," is largely dependent on the basic data sources used in the analysis. At this point of technology development, the potential of combining conventional surface and radiosonde observations with digital satellite (imagery and sounding) and radar imagery (Doppler and conventional) offers promise of substantial improvement in our ability to more completely describe the state of the atmosphere (nowcast). That potential is greatest in mesocale meteorology with geosynchronous satellite (GOES-type) data (which provides practically continuous views of the same geographical area at half-hour intervals), with the use of minicomputer-based interactive graphics systems, and with the viable emergence of meso- and cloud-scale NWP models.

A study completed in 1984 examined the relationship between geosynchronous satellite and radar depictions of the same "weather system" to develop procedures which could be applied to satellite data to estimate the weather distribution in "radar-denied" areas. There is the potential of applying these algorithms in battlefield weather systems using either GOES-type or DMSP-type imagery to obtain area estimates of rainfall. The McIDAS facility (see Satellite Meteorology above) was used to archive manually digitized radar

(MDR) and GOES imagery (visible and infrared) for days and regions of moderate-to-deep convection, which formed the basis for the histogram-based algorithms. Various indices of brightness and infrared temperature were evaluated for MDR box-size areas (40 km × 40 km). The best discrimination between substantial radar areas and less substantial areas was achieved with spatial smoothing of the satellite imagery to represent regions of about 400 km^2 in which infrared cloud-top temperatures are colder than –45C° C. Further improvement in discrimination is realized in regions where the satellite brightness represented reflectivity values of 85 percent or greater.

The products of the nowcasting studies are computer-generated descriptions of the state of the atmosphere derived from successively more complete data sets. They provide the basic input to short-range (mesoscale) prediction models. Models must be tailored to: (1) the limitations of the nowcast data sets, (2) the forecast range of interest, (3) varying levels of sophistication in the treatment of the physics of the prediction problem, and (4) limited computer capacities. The principal determinant for the approach taken for a particular forecast model is forecast range. For the very short-range prediction (0 to 6 hr), fairly simple extrapolation/translation models are most appropriate because more complete numerical models can never be expected to be executed operationally in a timely enough manner to be useful. For the 3–12 hr period, mesoscale numerical models can draw on the space and time detail included in nowcast-initialized fields enhanced by satellite and/or radar inputs. In the range from 3–6 hr, however, it is uncertain where simple techniques are overtaken by numerical models in terms of forecast accuracy. The mesoscale models can account for moisture-related development and decay processes that are driven by synoptic-scale processes and/or local forcing, processes which become more important in time. The main constraint placed on these model development efforts relates to their potential application within planned AWS minicomputer systems with or without an interactive graphics capability. This means that the techniques under consideration are either objective (completely computer-generated) or interactive (assume a trained forecaster using computerized procedures to assist in the prediction solution). The goal, again, is to develop models for point and area forecasts of winds and sensible weather for time periods out to 12 hr.

Mesoscale NWP Modeling: For longer range forecast intervals (3-12 hr), increasingly sophisticated numerical models which can be implemented within a minicomputer environment in near real-time are under development. Here, again, we are proceeding towards a series of numerical models designed to handle specific weather situations, because mesoscale weather systems are largely driven by two classes of effects: (1) local or terrain factors and (2) transitory mesoscale/synoptic scale influences. A physically-based advection model for nocturnal convective clouds and forecasting has been developed based on principles of anabatic flow of air with large wet-bulb potential temperature over sloping surfaces. The diagnosis of active convective regions based on this model, coupled with an interactive trajectory scheme designed for minicomputer graphics application, is an example of the kinds of simple, adaptable techniques under development for the Automated Weather Distribution System (AWDS). A particular study of a local factor model involved the application of a two-dimensional moist numerical model to investigate the dynamics of thunderstorm outflow producing gust-front currents analogous to atmospheric density currents. By using a new form of the equation for density current speed, this model showed the effects of the environmental wind relative to the storm and the vertical wind shear on both the propagation of the gust front and the depth of the outflow. The effects of moisture and other circula-

tion attributes on convection formation and evolution were simulated. The generation of an arc cloud is found to result in a less intense and slower gust front.

A research program to develop generic mesoscale NWP models for cloud and precipitation forecasting applications at both AFGWC and through AWDS in base weather stations was initiated in FY 84. The basis of these studies is a three-dimensional hydrostatic, moist primitive equation model which, in its present configuration, is initialized with a single radiosonde and modified by underlying terrain variation. The model structure consists of 16 terrain-following surfaces and a square domain spanning 500 km with a grid resolution of 20 km. Initial testing of the model using special data collections in central Texas during NASA's AVE-VAS program has revealed a number of model weaknesses. Research currently underway is pursuing alternative model initialization approaches involving objective surface analyses to more properly represent horizontal variability in the boundary layer, an evaluation of two- and three-dimensional lateral boundary conditions, development of procedures to "nest" the mesoscale model within a regional or limited-area model, and alternative time-integration schemes to improve computational efficiency. Studies of the utility of AFGWC cloud analyses (so-called 3-D Nephanalysis) to initialize the model's moisture distribution have been undertaken (see Satellite Meteorology above).

Interactive Graphics Systems Studies: A major modernization of AWS weather stations is underway with a planned inventory-wide implementation later this decade. The Automated Weather Distribution System (AWDS) will place interactive graphics terminals with access to gridded analysis and forecast products of AFGWC and conventional surface and upper-air observations in each weather station. Very short range (0 to 6 hr) forecast-technique development in the Atmospheric Sciences Division in support of AWDS is proceeding mainly along two lines. In the first case, interactive procedures to assist the operational forecaster in using a system like AWDS for terminal and local area predictions are being developed and evaluated. McIDAS was used to systematically evaluate specific, but generic, weather situations to formulate interactive decision-assistance procedures. Two mesoscale forecast experiments (MFE) were undertaken using the McIDAS system to evaluate (both quantitatively and qualitatively) certain aspects of interactive systems, specific data sources, and forecaster performance during major winter-storm episodes in the Northeast. Forecasts of wind, cloud cover, ceiling and 6-hr Quantitative Precipitation Forecast (QPF) for periods out to 10 hr in both probability and deterministic forms were evaluated. The MFE were designed to assess: (1) the value to forecasters of existing and new software capabilities tailored to the mesoscale, (2) the importance of data sources like MDR and GOES, and (3) the difficulties and/or advantages in using interactive systems for short-range terminal forecast preparation. These experiments confirmed the need for user-specific data plotting and analysis software, an easily-accessible data base and, particularly, the routine availability of computer-compatible geosynchronous satellite imagery.

With AFGL support, the NOAA Prototype Regional Observing and Forecasting Service (PROFS) program conducted a series of extensive forecast experiments in the Boulder, Colorado, area using operational and research meteorologists. Forecasts of severe thunderstorms and tornado watch and warning were augmented with aviation terminal forecasts of peak wind, minimum visibility and precipitation amount for time periods out to 2 hr. The forecasters' performance and effectiveness were evaluated against various data sets ranging from conventional products and operational capabilities to surface mesonetwork observations, Doppler weather radar, and rapid-scan satellite

imagery. All data sets were processed and displayed to the forecaster through state-of-the-art computer graphics technology. Experiments were conducted in real-time and in displaced real-time over a 3-year period using full data sets archived on magnetic tape/disk and replayed through the PROFS system for forecaster evaluation.

The search for skillful simple terminal-forecast techniques for minicomputer application is an elusive one. After substantial experimentation, the current focus is on advection-based techniques that seek to account for terrain-based nontranslatory effects, diurnal considerations and other local peculiarities that can be objectively identified. Double advection models based on 500-mb space-averaged winds advecting the 850-mb flow field to determine upwind trajectory points for 1–12 hr forecasts generally yield better forecasts than simpler models. The advantages of using more highly resolved objective analysis techniques to specify initial conditions are both positive and negative (in the sense that much of the mesoscale detail that is retained in the analysis appears to be transitory and not amenable to advection processes).

BOUNDARY LAYER METEOROLOGY

The planetary boundary layer extends from the earth's surface to a height of about 1.5 km. By definition, it is that layer of the atmosphere from the earth's surface to the geostrophic wind level, or to that level at which the frictional influences of the earth's surface become negligible.

Understanding the structure and dynamics of this layer is important to the Air Force since so many Air Force systems operate within it. Improved techniques for the detection and prediction of meteorological elements in this layer are required to support Air Force systems and operations such as advanced military communication and surveillance systems, and operations that may be impacted by inadvertent or planned toxic chemical releases.

Anomalous Microwave Propagation: Surveillance radars, digital microwave radios on long line-of-sight (LOS) communication links, and tactical digital troposcatter radios all experience significant anomalous propagation events that limit these systems from achieving desired performance objectives. An atmospheric refractivity "event" that can adversely affect one of the above systems may result in enhanced performance on another and be neutral in its effect on a third. Specific system geometry or its method of deployment is very important in determining the magnitude of the effects of these refractivity events.

The measurement program of atmospheric structure with portable radiosonde measurement systems that began in 1981 with the cooperative measurements on Defense Communication System (DCS) operational links in Germany continued during the summer and fall of 1983 in a joint radio-propagation/meteorological-measurement program with Rome Air Development Center (RADC). The test path was from Saddleback Mountain, Deerfield, New Hampshire, to Prospect Hill, Massachusetts. RADC obtained delay spread data from a channel probe and refined angle-of-arrival measurements from their movable 30 ft dish at Prospect Hill. Correlation of meteorological measurements of duct height and strengths with delay spread and angle-of-arrival data was accomplished. In addition, computer-generated ray trace data through measured refractivity data was validated as a tool to simulate and design line-of-sight links and evaluate multipath effects on digital radio performance.

In January, 1982, a refractivity measurement program was initiated with ESD and MITRE to study performance of digital troposcatter radio performance under a variety of climate and terrain conditions. This program required the acquisition and use of a fast-response microwave refrac-

tometer to measure the microwave refractive-index structure function (turbulence) in the atmosphere from 30 m above ground to 3.5 km. The refractometer was mounted in a chartered light aircraft. Aircraft measurements have been used in conjunction with troposcatter radio tests in Florida, Arizona, and over the North Sea. The line-of-sight ray trace model has been adapted for modeling troposcatter radio.

The diverse climatic conditions of these joint meteorological radio-propagation measurements have resulted in a significant increase in our knowledge of atmospheric structure effects on troposcatter radio performance. Reports on the radio performance work are being prepared jointly with MITRE. The troposcatter ray-trace development work will be reported separately by AFGL.

Toxic Chemical Dispersion: Accidental chemical spills can occur anytime when storing or transporting chemicals, whether it be a civilian or military operation. For emergency response planning and operations, a model is needed for predicting the hazard area resulting from a spill.

A program was started during the two-year period of this report to review the current diffusion models available, including the Air Force's Ocean Breeze/Dry Gulch (OB/DG) diffusion model. The Shell Oil Company SPILLS model (a Gaussian puff model) was chosen as a good state-of-the-art model. The hazard distances derived with this model were compared with those distances determined from the OB/DG model for a variety of meteorological and spill conditions. The major discrepancies occurred during stable conditions when the OB/DG model produces much shorter hazard distances than the SPILLS model. Modifications were then made to the SPILLS model to include a continuous stability parameter instead of using discrete stability categories. The stability parameter was also made a function of the surface roughness. A comparison of this model showed much better agreement with the OB/DG model, except, as before, in the very stable cases.

The source strength is an important input parameter in the diffusion models. A study was made of the various techniques used in different diffusion models for calculating the evaporation rate from a liquid pool. The study showed that computed source strengths can vary up to a factor of four depending on the technique used.

Since atmospheric dispersion behaves differently over complex terrain, an effort was initiated to develop a fine scale terrain-induced surface wind flow model. An existing model was obtained from the Army Atmospheric Sciences Laboratory. This model is now being evaluated and future plans call for mating this model with a diffusion model.

Boundary Layer Modeling: To better understand the dynamic and physical processes that take place in the planetary boundary layer, a three-dimensional, second-order turbulence model is being developed. This model will include uneven terrain and non-uniform surface distribution of sources and roughnesses. The model will be a generalized model that can be tailored to address specific problems such as defining areas where anomalous propagation might occur, predicting fog and the dispersion of toxic chemicals.

Prediction Model for Snow Attenuation: Increased use of shorter wavelengths in Air Force communication and surveillance systems makes them more vulnerable to weather conditions, including attenuation caused by falling or blowing snow. Data gathered during the Tri-Service Snow ONE-A field program were analyzed to produce attenuation statistics from which a prediction model could be derived. As reported in AFGL-TR-84-0040, snow situations can be grouped into three classes: moderate to heavy snowfall; light snowfall; and snowfall or blowing snow in which the variations were caused by heavy, variable winds. In all cases, a mathematical model based on the theory of Markov processes could fit the observed

data and provide the basis of an attenuation prediction model.

SYSTEMS DESIGN CLIMATOLOGY

Air Force systems and materiel must be designed to operate in, and withstand, atmospheric extremes that have a vital effect on the successful accomplishment of the Air Force mission. Overdesign may be uneconomical or even ineffective, whereas underdesign can result in failure, with possible loss of life and equipment. As a result, materiel and systems design require careful consideration of various atmospheric elements, including their variability and extremes. Limitations of current meteorological data make it necessary to develop theoretical and empirical models, or algorithms, and to improve the utility of available climatic information as well as to provide more accurate estimates of the structure and variability of the atmosphere. Consequently, climatological research is continuing in order to better describe the atmosphere and its effect on Air Force plans and the design and operation of equipment.

Middle Atmosphere Climatology: Atmospheric density and its variations can be significant factors in the design, operation and deployment of aerospace vehicles. For example, density uncertainties of as little as 2 percent will cause errors in heights (determined from density) ranging from 125 m at an altitude of 20 km to 160 m at 60 km. Consequently, a precise description of atmospheric structure which includes a detailed knowledge of temporal and spatial variations of density at these altitudes is especially important to autonomous navigation of aerospace systems as well as for reentry vehicle design and operation.

Estimates of the time and space variations of middle atmosphere density for regions between the equator and 65° latitude were determined. Emphasis was placed on altitudes between 20 and 60 km for horizontal distances out to 200 nmi (370 km) and time periods of 1 to 72 hr.

Strong winds have been a potential meteorological problem for many decades. In recent years, they have proved to be very important in missile and other aerospace vehicle design and operations. Extreme winds, for example, can be a significant factor during staging, that is, separation of a booster from its main vehicle on ascent, because flight control of aerodynamic vehicles may be lost temporarily during this maneuver. Windspeed extremes in the northern hemisphere at altitudes of 30 through 60 km were described in an AFGL technical report (AFGL-TR-83-0029) which presented maps of monthly 90, 95, and 99 percentile scalar speeds (10, 5, and 1 percent extremes).

Environmental Simulation: During the two-year period of this report, the study of the spatial and temporal aspects of climatology was shifted, in part, to the stochastic portrayal of "snapshot" pictures of the weather, in particular to cloud scenes as might be viewed from the ground or from a vehicle in outer space. This emphasis was dictated by the requirement for synthetic fields during war games in which cloud-free lines-of-sight (CFLOS) and cloud-free intervals (CFI) play key roles. The simpler problem, to generate a sequence of joint interrelated local events, was solved by assuming a Markov process of weather events. This procedure can now be used to produce time variation of joint events, such as ceiling and visibility at one station, or two ceilings at neighboring stations.

In the portrayal of the areal extent or coverage of clouds, a new model was conceived to replace Gringorten Model B. The new, computationally faster model is easily applied to produce a horizontal picture of clouds as well as vertical cross sections. The probability of partial areal cloud cover, from zero to full overcast in areas of varying sizes, are reproducible by this model. It was first developed for use in a

single horizontal plane, then modified and enhanced to operate in three dimensions, thus allowing the generation, stochastically, of vertical cross sections of clouds. It was also realized that the depiction of a field of clouds could be modified realistically with time, preserving the Markov process at individual stations. This latter accomplishment, however, prompts further investigation to incorporate meteorological phenomena such as advection into the temporal changes.

One most important advance was made in developing computer algorithms for estimating the probability of fractional cover of events in a space which will replace the previous graphical solutions. Empirical algorithms were formulated to estimate the probability that a weather condition will exist over a given area or length, or fraction of an area or length. These equations do not represent an analytical solution since they were developed using a Monte Carlo process, and need to be tested to determine their strengths and weaknesses.

The need to determine climatologies over targets and battlefields which are data-void or data-denied prompted a continuation of research in this area by the University of Central Florida. The studies centered on describing the climatologies of visibility for locations in Germany. A model using the two-parameter Weibull distribution and incorporating physical features of the region was determined to be superior to others tested. Investigations were conducted to determine the physical meaning of these parameters and to establish the most accurate and cost effective methods of estimating them. The model was then extended to Norway using a 51 station developmental sample, with good results.

Climatic Data for Equipment Design: An effort is underway within the Department of Defense to revise military specifications and standards in the program area of Environmental Requirements and Related Test methods (ENVR). It was initiated because of misapplication and misuse of these documents by both government and industry. Part of this undertaking involves the revision of MIL-STD-210B, "Climatic Extremes for Military Equipment," which provides climatic data for the design of equipment intended for worldwide use. AFGL is responsible for revising this document, which is being expanded to include regional climatic information, and temperature and density profiles, from the surface to 80 km, based on extremes at specified altitudes. Also included will be applicable inputs from the research presented in the section on rainfall rates. Most important, however, the philosophy on application of the data is being changed to reflect current DoD acquisition policy on tailoring for the design and testing of materiel. This will enable the user to determine the appropriate climatic data needed to meet the operational requirements of each system or item under development. A first draft of the revised standard is scheduled for completion by FY 86.

Rainfall Rates: The Air Force required frequency distributions of instantaneous, or 1-min, precipitation rates at locations throughout the world to determine design and operational requirements for many types of equipment. Precipitation, especially at heavier intensities, attenuates microwave signals to and from Air Force systems used in satellite detection and tracking, communications, air traffic control, reconnaissance, and weaponry. Erosion due to rain affects helicopter rotor blades, leading edges of aircraft and missiles, and fuses on airborne ordnance. Intense rainfall can cause jet engines to malfunction and can penetrate protective coverings on exposed electronic and mechanical materiel.

Since actual observations of 1-min precipitation rates are scarce, an empirical model for estimating monthly 1-min rain rate statistics was developed from a special data set. The model was used to develop Northern and Southern Hemisphere atlases of 1-min rain rates. Also, the University of Illinois completed a study on

how rain rates vary along lines and within areas in different climatic areas. Work is currently underway to determine vertical profiles of extreme rainfall rates up to an altitude of 20 km. These profiles will include associated dropsize distributions and liquid water content.

Temperature and Density Profiles: Information on expected extremes of atmospheric temperature and density are required for developing all types of airborne vehicles ranging from helicopters and airplanes to sophisticated aerospace systems. Such data are particularly important at altitudes from the surface to approximately 80 km. Existing model atmospheres either do not adequately address low probabilities of occurrence, or present envelopes of extremes at numerous altitudes that could not possibly occur simultaneously. Therefore, model profiles were developed based on 1 and 10 percent warm and cold temperatures and 1 and 10 percent high and low densities occurring at the worst locations in the world (excluding Antarctica) during the worst month. The profiles from the surface to 80 km are based on extremes that occur at 5, 10, 20, 30, and 40 km. Associated, internally consistent, hydrostatic profiles of density are included with the temperature profiles, and associated temperatures are provided for the density profiles. The profiles represent conditions typically associated with the extreme values at the specified levels.

Thermospheric Density Variability: Persisting deficiencies in understanding lower thermosphere neutral-density variations continue to impact Air Force operations that require knowledge of aerodynamic drag effects on space vehicle trajectories. These requirements include satellite tracking and reentry predictions by Space Command and the control and operation of DoD mission satellites by Space Division's Air Force Satellite Control Facility. Extension of the Air Force Reference Atmospheres, 1978, to 200 km, from their present upper boundary of 90 km, will provide users with state-of-the-art understanding of this region.

In the 90-120 km region, all available data from ground-based incoherent scatter radars and from rocket probes are being collected. Zonally averaged values and climatological variations of temperature, pressure and density are being developed as a function of altitude, latitude and season. The models will be "matched" to those selected above 140 km. Statistical evaluations of thermospheric models are being carried out using direct density measurements obtained by AFGL satellite accelerometer experiments. Data from seven accelerometer systems flown from 1974-1982 have been incorporated into the most extensive density-data base available for thermospheric studies. Two recent additional instruments have provided data from the last half of 1983 to the first quarter of 1984 and during the last half of 1984, respectively. Results from these two flights and the present data base will be used to describe accuracy of the selected models as a function of altitude, latitude, day of year, season, solar flux and geomagnetic activity.

Several other studies utilizing the accelerometer data were completed. NASA funded an independent study of the aerodynamic drag environment that could be encountered by their proposed Geopotential Research Mission. This involves flying two satellites for six months in 160 km circular polar orbits. Our study revealed that the MSIS 77 model provided an acceptable error margin for average density. Cross-track winds in excess of 1 km/sec at high latitudes were identified as a potential error source for the guidance and control system. Another activity involved accurately determining aerodynamic drag values during selected periods for Defense Mapping Agency use in satellite positioning studies. The first evaluation of a potential high-latitude heating indicator based on direct measurements was also accomplished. A Total Auroral X-ray Intensity (TAXI) index developed by Aerospace Corp. from bremstrahlung x-ray measurements was correlated with accelerometer density data. The TAXI in-

dex did not provide improved estimates of satellite drag compared to conventional ground-based indicators of geomagnetic activity. The study pointed out the need for accurate knowledge of atmospheric dynamic processes as well as both Joule and particle heating. A detailed study of accelerometer density and wind measurements during a 1979 geomagnetic storm revealed several new features of atmospheric dynamics. The winds showed a 2-cell high latitude pattern that was better ordered in geomagnetic, rather than geographic, coordinates. Wind speeds did not correlate strongly with the Kp index, although for very quiet periods they were typically of the order of 150 m sec^{-1}, while during the storm period they were 400-600 m sec^{-1}. Daytime density variations were larger at high geomagnetic latitudes and smaller and less well-defined at lower latitudes, while the nighttime response was better defined equatorward than poleward. This day/night difference is attributed to a reinforcement of southward winds on the nightside associated with the combination of high latitude heating and solar EUV heating.

A new approach to forecasting density variability due to storms has been initiated using Laboratory Director's Funds. This study ties together theoretical thermospheric general circulation models, improved estimates of high-latitude heat sources and direct density measurements. This is part of a systematic attempt to represent atmospheric variability by including new physical concepts in models rather than by attempting to tune existing models.

Dynamical-Chemical Models and Turbulence: Work on the dynamical-chemical atmospheric models was terminated in 1983. A one-dimensional model of the dynamics and composition of the mesosphere and lower thermosphere was completed. The model is based on a numerical solution of a large set of partial differential equations for the conservation of mass and momentum for individual gases in an atmosphere with constant temperature and turbulent diffusion profiles. The model describes the spatial and temporal distributions of 56 neutral and ionic atmospheric species involved in 215 chemical reactions. The three-dimensional effort was to make use of the dynamical schemes and simplified chemical treatments embodied in an existing three-dimensional Stratospheric Circulation Model.

A quantitative description of turbulence in the 90 to 120 km altitude region was completed. It involved the computer analysis of chemical tracer releases to determine Fourier turbulence spectra and configuration space statistical descriptors of turbulence and atmospheric winds. An analysis established a probable, long-term relationship between turbopause height and solar 10.7 cm flux. The results suggest a lagging 11 year cycle of motion of the turbopause altitude in response to this flux. In another effort, turbulent energy balance and an altitude-invariant non-dimensional relation of turbulent heat flux were utilized to obtain vertical turbulent diffusivities from bodies of data consisting of winds and temperature in the upper atmosphere. From these data, the latitudinal variabilities of stratospheric and mesospheric turbulent diffusivity in the northern hemisphere were derived. This is the only analysis to date that incorporates the effects of energy transfer to and from the mean motions.

The index of refraction of radio and optical waves in the lower atmosphere has also been examined. Relations have been derived between neutral density fluctuations and radar and optical reflectivity that result in reasonable values of C_n^2, the refractivity structure constant. An alternative formulation of C_n^2 has also been derived by using the mean atmospheric-density structure and the rate of dissipation of turbulent energy.

Density Models and Predictions: Support was provided to a government organization to predict the reentry of the Cosmos 1402 surveillance satellite. This was a high interest satellite, both because of its

mission and because it contained a nuclear reactor to provide power. Information was provided on upper atmospheric density fluctuations that could affect predictions of satellite reentry times and locations. It was also pointed out that the first major vehicle to reenter would be the larger, lighter satellite body and that the second vehicle would be the smaller, heavier radioactive reactor core. Reentry predictions were made at AFGL on a realtime basis. The reentry time of the large satellite body with quiet atmospheric conditions was predicted with a very small error. Unfortunately, a magnetic storm occurred before the reentry of the reactor core and, as a result, it reentered earlier than predicted. This points up the need for improved density models for storms and also the need for improved forecasts of their occurrence and magnitude. Existing models of the thermosphere also do not respond accurately when the solar flux changes rapidly. An empirical density model has been developed which shows improved performance under these conditions and equal performance with other models under quiet conditions. It makes use of daily, 27-day average and 81-day average values of the solar decimetric flux, $F_{10.7}$.

Another important application of density specification is to aeroassist technology. A major contribution was made to the work of the joint Air Force-NASA Aeroassist Working Group, which oversees research to develop the technology of using aerodynamic forces to modify the trajectories of space vehicles. A major application of aeroassist technology being investigated at present is to reduce the velocity of orbital-transfer vehicles as they return from high-Earth orbit and rendezvous with the Shuttle in low-Earth orbit. To reduce the velocity, the vehicle would make one or more braking passes through the upper atmosphere at a minimum altitude of about 70 km. The big questions are how predictable and how variable is the atmospheric density in the altitude region from 70 to 110 km. Some of the Shuttle flights have exhibited the effects of large rapid fluctuations in density during reentry. A detailed presentation of AFGL's information on this topic was provided to the Working Group.

Major contributions were made to the planning and initial design of the Stellar Horizon Atmospheric Dispersion (SHAD) satellite and balloon experiments. The objectives of the SHAD technique are to track stars through the Earth's atmosphere to provide navigation data for missiles or spacecraft and to measure stratospheric density. A balloon version of SHAD was launched. The experiment locked on to, and tracked, several stars. The feasibility of the technique was demonstrated and the results were used to refine the design of the satellite instrument.

The Proceedings of the "Workshop on Comparison of Data with the COSPAR International Reference Atmosphere (CIRA 1972) and Proposed Revisions" (held at Ottawa, Canada, in May, 1982) were edited and published in 1983 as a volume in the journal *Advances in Space Research,* entitled "The Terrestrial Upper Atmosphere." The volume contains data and models of the structure of the middle atmosphere, including the southern hemisphere. Density, composition, temperature and wind data for the thermosphere are included, in addition to thermospheric models and their comparison.

An invited review entitled "Recent Advances in Upper Atmospheric Structure" was presented at the COSPAR meeting at Graz, Austria, in July, 1984. A possible quantitative explanation was presented of the semiannual variation in the density in the lower thermosphere in terms of a semiannual variation in the globally averaged vertical energy carried by tides propagating from the lower atmosphere into the thermosphere. The effect is primarily due to seasonal changes in the distribution of water vapor in the lower atmosphere, and in the solar declination angle and Sun-Earth distance.

A new empirical model of thermospheric variations with geomagnetic activity was

developed, incorporating variations with local magnetic time, latitude, dependent terms which vary with the magnitude of the geomagnetic disturbance, and an altitude-dependent expression for the equatorial wave. A new index has been developed which shows promise of being better than Kp for representing variations of thermospheric species with geomagnetic activity. The index, denoted by ML, is defined as the integral of time-weighted values of AL, which is an auroral index measuring the strength of the westward electrojet and is related to Joule heating. A comparison was made of the temporal variations of measured values of solar UV flux (185–205 nm), modeled UV fluxes based on solar Ca-K plage data, sunspot numbers (R), and 10.7 cm flux. Some significant differences were identified. Thermospheric properties should be studied to determine if their variations have higher correlations with the UV indexes than with $F_{10.7}$ and R.

The Atmospheric Sciences Division has been guiding the planning and development of a new set of COSPAR International Reference Atmospheres. The work has been divided between two Task Groups. One is concerned with the middle atmosphere and the other with the thermosphere. The Middle Atmosphere Task Group is preparing reference atmospheres and text for the altitude region from 20 to 120 km. For the first time, the reference atmospheres for the 20 to 80 km altitude region will be based on satellite remote-sounding temperature and wind data, as well as on in-situ measurements. This has the added advantage that the first truly global atmospheres can now be prepared for this region. The models for the 80 to 120 km region will be based on data from rocket, incoherent scatter, and optical measurements. The text will include discussions of the data, tides, planetary and gravity waves, turbulence, and variability. The thermospheric part will include a set of empirical reference atmospheres, representative theoretical models, magnetic storm models, a discussion of turbopause effects, and reviews of in-situ measurements, radar and optical measurements, and solar and geomagnetic storm indexes. A mean reference atmosphere will also be provided.

Jacchia-Bass Model Modifications: The continuing need for improved accuracy in satellite orbit and reentry predictions results in the need for improved models of thermospheric density variations. A comprehensive tidal model, based on the Forbes tidal theory, was added to the Jacchia-Bass model (a simplification of the Jacchia 1977 model). This tidal model includes both diurnal and semidiurnal variations in total mass density. The original model does not include any semidiurnal variation, which is a major limitation since this variation dominates in the lower thermosphere.

GROUND-BASED REMOTE SENSING

Virtually every Air Force operation and every surveillance, weapon and communication system is affected by the environment in which it must function. To meet the continuing need for more precise and timely weather support for these operations and systems, the Atmospheric Sciences Division develops techniques for the remote sensing of adverse environmental conditions and the incorporation of this information into precise weather advisories and forecasts for time scales up to several hours.

Progress over the past two years has centered on the development of (1) microwave Doppler weather radar techniques for the detection and warning of wind-related hazards, (2) coherent polarization diversity weather radar techniques for the measurement of hydrometeor characteristics, (3) airborne electrostatic sensors for the location of hazardous electric charge centers and lightning, and (4) combined weather radar and satellite techniques for the measurement and forecast of precipitation along an arbitrary path.

Automated Doppler Weather Radar Analyses: Conventional weather radars, of the type presently in operational use by the nation's weather services, do not have the ability to directly measure wind-related atmospheric phenomena. The existence of wind-related hazards such as shear, turbulence, mesocyclonic vortices, tornadoes, and converging or diverging wind fields is inferred from the effects of the hazard on the distribution of precipitation within the storm system. Such effects, if present, occur late in the life-cycle of the phenomenon. Operational forecasts of these phenomena therefore suffer from poor probabilities of detection, very high false-alarm rates, and virtually no warning time.

Doppler weather radars promise to revolutionize the operational detection and warning of atmospheric hazards through their ability to measure the wind speed and direction within a storm or in the clear atmosphere, in addition to the parameters measurable by a conventional radar. The added capability to remotely measure winds provides the meteorologist with a means of making a precise determination of the nature and existence of a hazard early in the life cycle of the phenomenon. For the Air Force commander, these new capabilities will yield forecasts with the precision and timeliness necessary to minimize the impact of severe storms on Air Force systems or missions.

The Air Force has joined with the National Weather Service and the Federal Aviation Administration to develop a new operational Doppler weather radar for their joint use. A new next-generation weather radar (NEXRAD), which is in the second phase of a three-phase procurement, is expected to be deployed in approximately 170 locations throughout the continental United States and selected locations overseas by the end of this decade.

AFGL scientists pioneered in developing much of the technology which comprises NEXRAD, and they continue to develop new capabilities to improve the effectiveness of the eventual use of the system by the Air Weather Service. Major efforts include the automation of many of the manual interpretive techniques and the development of new algorithms for the detection and warning of additional storm hazards. The various algorithms in process of development are not intended to robotize the radar input to severe weather warnings. The capabilities of a human analyst are needed to recognize subtleties in patterns, to assess the significance of information which transcends the algorithm models, and, most important of all, to make the decision to issue a warning. On the other hand, even the most experienced and most intelligent forecaster cannot deal adequately with the immense volume and rate of raw data supplied by a Doppler weather radar. An optimum sharing of work among the automated algorithms and the human analyst is evolving, with the computer performing the routine analytical tasks and alerting its human partner to events which require interactive efforts.

An investigation into the remote detection of in-cloud turbulence that affects aircraft has resulted in a method for use with radar which provides for the detection and classification of turbulence as hazardous and nonhazardous to aircraft. This scheme was developed after analysis of thirty-four aircraft and radar data sets, highly coordinated in space and time, acquired during aircraft penetrations of thunderstorms during the summers of 1981 and 1982. AFGL joined with NASA Langley Research Center and NASA Wallops Flight Center in a cooperative storm-hazards program at Wallops Island, Virginia. Multiwavelength ground-based tracking and Doppler radars were used, as well as NASA F-106B lightning strike and turbulence detection aircraft. Radar Doppler spectrum-variance data were employed with a model in which the strength and range of spatial scales of the turbulence field are defined in terms of the eddy dissipation rate and the maximum turbulence eddy size. Proper classification of

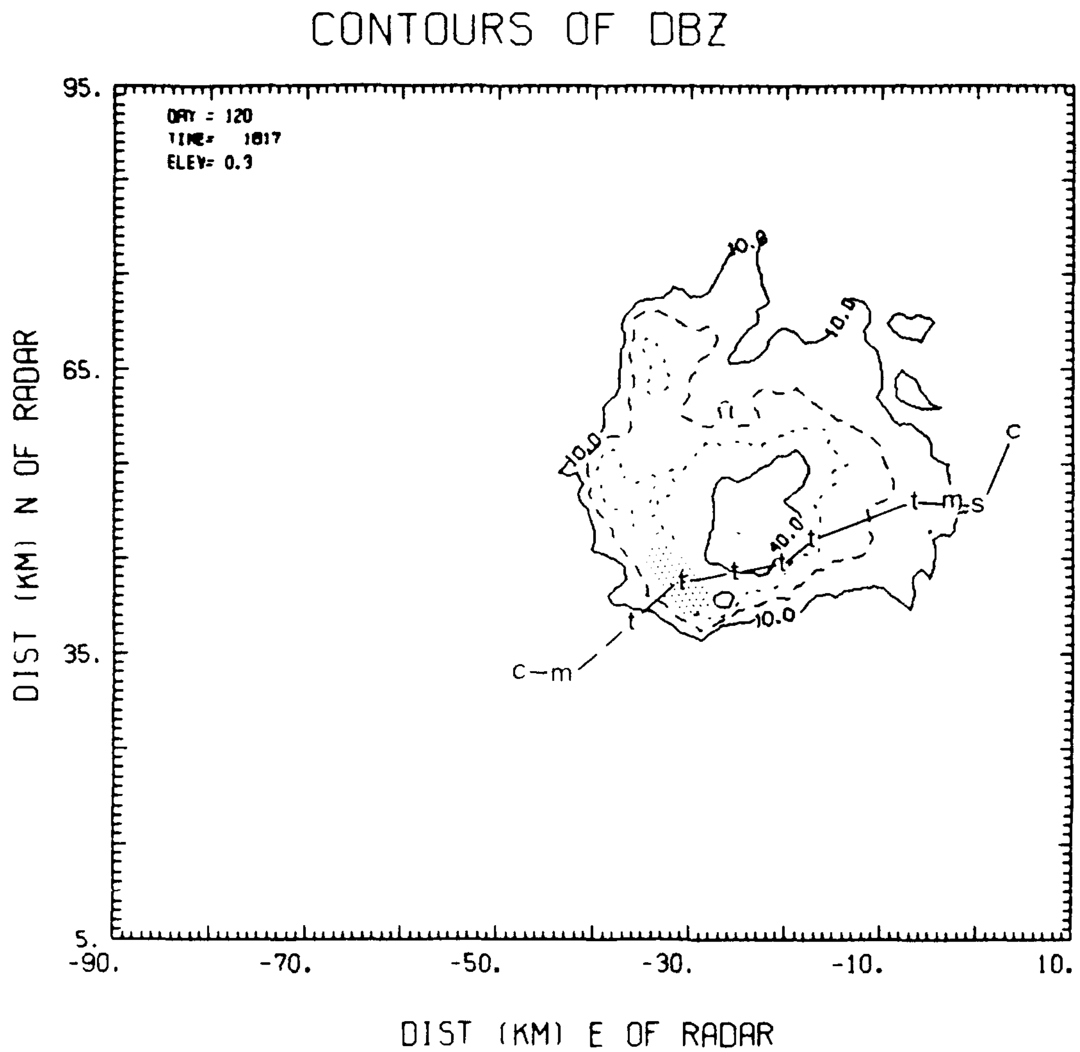
turbulence severity into individual levels of light, moderate, heavy, and severe intensity was difficult and could only be accomplished if a mix of maximum eddy sizes was used. However, a composite classification scheme with a moderate composite class (all turbulence with moderate or greater intensity) and a heavy composite class (heavy and severe intensity) was shown to provide an easy and reliable method for discriminating between significant nonhazardous and hazardous turbulence. This simpler and more uniform approach requires only one maximum eddy size, the value of which lies in the range from 1 - 4 km. The technique returns reliable information over all areas where the measured radar Doppler spectrum parameters are meaningful. For typical weather radars, this results in reliable turbulence-hazard detection within maximum ranges of 50 - 150 km from the radar location.

Some of the earliest observations of tornadic storms with Doppler radar revealed a distinctive signature characteristic of a larger circulation associated with the tornado. This larger circulation has been called the mesocyclone. Its signature is observed in nearly all data collected by Doppler radar and is often seen up to 60 min before tornado touchdown (see the figure). While the eye-brain recognition system is extremely adroit in the detection of the mesocyclone signature, the effort involved is extensive. Research has consequently been directed towards the development of an automated mesocyclone detection technique.

An algorithm has been developed that reliably detects several types of circulations within intense thunderstorms. It will detect and distinguish between cyclonically and anti-cyclonically rotating mesocyclones and tornadoes, as well as concentrated areas of convergence and divergence. It is also able to estimate the momentum and energy associated with these circulations. The detection of the mesocyclone has considerable warning potential, and this algorithm is the first to incorporate consideration of the variable resolution of the radar with range. It is therefore able to identify features at far ranges without triggering an unacceptable number of false alarms close to the radar. The mesocyclone-tornado vortex algorithm has been applied to several severe storms observed by Doppler radar in Oklahoma and New England. Output from the analysis package has been compared with confirmed observations of tornadic activity and the results have been excellent. The algorithm performed at least as well as the human observer, and in the case of a severe tornadic storm, the algorithm detected the tornado's parent mesocyclonic circulation approximately 25 min before the human observer.

While the mesocyclone detection algorithm appears to provide up to 60 min warning time before tornado events, longer lead times would provide an even greater service to the community in conserving lives and property. An effort was initiated to determine if the relative motion of small developing storm cells would reveal any indication of the development of a major storm system. This study resulted in the detection of significant convergence and rotation of cells during the development of an intense thunderstorm which produced several tornadoes, one of which was particularly devastating.

In a follow up to this study, an effort was made to automatically detect these small cells and to track their relative motions. An algorithm was developed which focused upon maxima in the reflectivity fields. This technique appears to reliably detect the small storms, but too many storms occurring too closely together prevent reliable tracking and hence usable estimates of convergence and rotation. However, two characteristics of these detected cells appear to provide a very good indication of the development of a "supercell" storm capable of producing severe damage, if not by tornadoes then by damaging winds, hail, or rain: (1) the number of cells within a storm and (2) a modified area average of reflectivity with-



Radar Observations of a Severe Storm in Central Oklahoma Which Produced Several Tornadoes. (Contours are of the reflectivity factor. The letters joined by lines indicate the track of the convergence zone (c), and mesocyclone (m), tornado (t), and shear (s) as detected by Doppler radar.)

in the cells. Further testing of this algorithm should provide stronger support of its utility.

Strong low-level wind shears pose a significant threat to air operations in the approach and departure corridors of air bases. Doppler radar is only able to measure that component of the wind which lies along the direction in which the radar beam is directed. However, it has been found that an analysis of the two-dimensional shear of that component results in a very good estimate of the location of significant shears and, hence, the location of potential aviation hazards. An algorithm has been developed which automatically detects such regions.

The basis for the shear algorithm is the computation of the shear of the radial component of the air velocity along the beam

(radially) and across it (azimuthally). The combination of these orthogonal components gives an estimate of the total shear. While this is obviously an underestimate of the shear of the total air velocity, it appears to be sufficient to provide a reliable estimate of the locations of the gust front. The locations are determined by computing one-dimensional shear-weighted centroids in two orthogonal directions and then merging these locations. The technique has been tested on several cases and preliminary results are promising.

An effort was initiated to extract operationally useful synoptic-scale wind-field information from asymmetric patterns of velocity acquired with a single Doppler radar. Current operational practice ignores these asymmetries by averaging them out and assuming that the resultant mean wind vector is uniform throughout the region scanned by the radar. However, in the real world, wind fields are not uniform. They are characterized by gradients in speed and by changes in direction. Synthesis of Doppler velocity patterns which would be observed in wind fields with linear speed gradients both along, and normal to, the direction of flow, and in a circular flow with constant speed, as well as combinations of these flow types, revealed the asymmetries and provided important clues for their analysis when encountered in nature. Unfortunately, the patterns for curved wind fields and for linear fields with crosswind gradients are similar in appearance and difficult to distinguish one from another. However, both wind-field types co-exist around a typical cyclone, with additive effects in the Doppler velocity pattern of asymmetry. Accordingly, a cyclonic threat index was developed which provides a combined indication of cyclone proximity (through wind field curvature) and intensity (through increase of wind speed toward the cyclone center). The cyclonic threat index should be an especially helpful diagnostic and forecasting tool for coastal radars because it could provide continuous surveillance of an offshore hurricane or severe extra-tropical cyclone.

An assessment of the utility of NEXRAD algorithms and products in both local and central forecast facilities was the objective of the three-season Boston Area NEXRAD Demonstration (BAND). BAND, a cooperative program between the Atmospheric Sciences Division and the NEXRAD Joint Program Office, used AFGL's 10 cm Doppler weather radar and data processing systems to send NEXRAD type weather radar products to future joint-agency users of these data. Operational users of BAND information included both central forecast facilities such as AFGWC at Offutt AFB, Nebraska, and the National Severe Storm Forecast Center at Kansas City, Missouri, as well as local forecast facilities, including the Pease AFB, New Hampshire, weather station, the NWS Boston Forecast Office and the FAA Nashua, New Hampshire, In-Route Center. More than 500 hours of data on all types of New England weather were provided in real time to the operational users for their evaluation of BAND Doppler Weather Radar products. Included in these weather events were severe wind and hail storms, tornadic storms, and larger scale stratiform rain and snowstorms. Operational results of these tests will form the bases of guidance to NEXRAD contractors concerning NEXRAD data products for both local and central facility users. Weather radar and supporting information from these tests will be utilized in the development of a variety of new software techniques for use with the forthcoming NEXRAD system.

Precipitation Characteristics: The microphysical properties of clouds and precipitation are of significant practical concern to the Air Force because of their effects on (1) the depolarization and attenuation of terrestrial and satellite communications systems, (2) the safe performance and even survivability of airframes in regions of hail or heavy icing, and (3) the erosion of reentry vehicles.

The need for remote-sensing techniques for characterizing the microphysical parameters of cloud and precipitation systems has led to the investigation and development of polarization diversity-radar techniques for deriving information on the size, shape, number concentration, orientation, and thermodynamic phase of cloud and precipitation particles. The polarization techniques rely on the fact that many types of hydrometeors are nonspherical and tend to orient themselves in a preferred way in response to aerodynamic or electrical forces. The hydrometeors thus constitute an anisotropic scattering and propagation medium. This characteristic of the medium has implications for the performance of surveillance, guidance, and communications systems in cloud or precipitation environments. The anisotropy of the medium makes it possible to use the amplitude, or power ratio, and relative electromagnetic phase of the received radar signals of opposite polarization to derive the average, or distribution, of the shapes and orientations of the hydrometeors. The polarization parameters, with the reflectivity and Doppler velocity parameters, and calculations of backscatter from water and ice particles permit the most comprehensive possible description of the scattering and propagation media from a single radar.

AFGL is adding a polarization diversity capability to the existing 10 cm wavelength Doppler weather radar to use for the development of these techniques and for the documentation of propagation and scattering effects on electromagnetic signals. Key features of this modification are an axisymmetric Cassegrain antenna for high isolation between orthogonally polarized signals and a high-power microwave switch to enable switching of the transmitted polarization on a pulse-to-pulse basis. Construction of the radar system is expected to be completed in 1985. Theoretical studies have continued, both in the interpretation of backscatter signal parameters and in the evaluation of system-error effects on the measurements. These studies have yielded a possible technique for determining wind shear within a radar sampling volume and for estimating the width of particle-size distributions.

Because of the increased backscatter from small water drops and ice crystals at shorter wavelengths, the polarization diversity techniques are also being evaluated for use with 8.6 mm wavelength radars. The measurement capability of these radars is being evaluated for possible use in the automation of weather observations beyond the capability presently available for the Automated Observation System (AOS). Experimental data from an 8.6 mm wavelength radar at the NOAA Wave Propagation Laboratory are being used for this purpose. Although signal attenuation precludes the use of millimeter wavelengths for long-range radar measurements in precipitation, the 8.6 mm wavelength data are an important counterpart to the 10 cm wavelength radar capability being developed at AFGL.

Electric Field Measurement and Lightning Warning: Lightning strikes to aircraft and spacecraft in the vicinity of thunderstorms constitute a significant hazard to Air Force systems and operations. An airborne electric-field measuring system was developed to provide information on the proximity and magnitude of electric charge centers and the likelihood of aircraft-induced lightning. The system, comprising four low-frequency electric field sensors, was installed on the F-106B lightning research aircraft operated by NASA Langley Research Center and operated in a three-year flight measurement program. The resulting data provided information on system performance under conditions of heavy rain, turbulence, and lightning strikes to the aircraft and on the effects of aircraft charging on the external electric-field components. System calibration parameters were also provided for derivation of electric charge distributions from the electric-field vector measurements. Although these results were promising, the program was terminated because of AFGL program and personnel realignments.

Short Term Cloud and Precipitation Forecasts: Satellite-to-ground ehf communications and electro-optical systems are adversely impacted by intervening clouds and precipitation. Current weather radar and meteorological satellite-based analysis techniques do not allow for short-term forecasts of the meteorological phenomena with the precision required for optimum operation of these systems. A new initiative is concerned with the development of combined Doppler weather radar and meteorological satellite techniques for the continuous real time monitoring of the spatial distributions of clouds and precipitation and for predicting the motions of these systems. This continuing effort is expected to provide continuously updated forecasts suitable for mitigating the impact of the atmosphere on electro-optical and ehf systems.

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SMYTHE, G.R., and HARRIS, F.I. (Systems and Applied Sciences Corp., Vienna, VA)
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USSAILIS, J.S., and BASSETT, H.L. (Georgia Inst. of Tech., Atlanta, GA)
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VONDER HAAR, T.H., HILLGER, D.W., and LIPTON, A.E. (Colorado St. Univ., Fort Collins, CO)
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WACHTMANN, R.F. (Systems and Applied Sciences Corp., Vienna, VA)
Characteristics and Behavior of Atmospheric Aerosols: Application to Prediction of Infrared Extinction
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WIELER, J.G. (Systems and Applied Sciences Corp., Vienna, VA)
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AFGL-TR-84-0282 (20 October 1984), ADA154968

WILLIAMS, G.M., BIRKENHEUER, D., and HAUGEN, D.A. (NOAA/ERL/ESG, Boulder, CO)
A Study of Mesoscale Probability Forecasting Performance Based on an Advanced Image Display System
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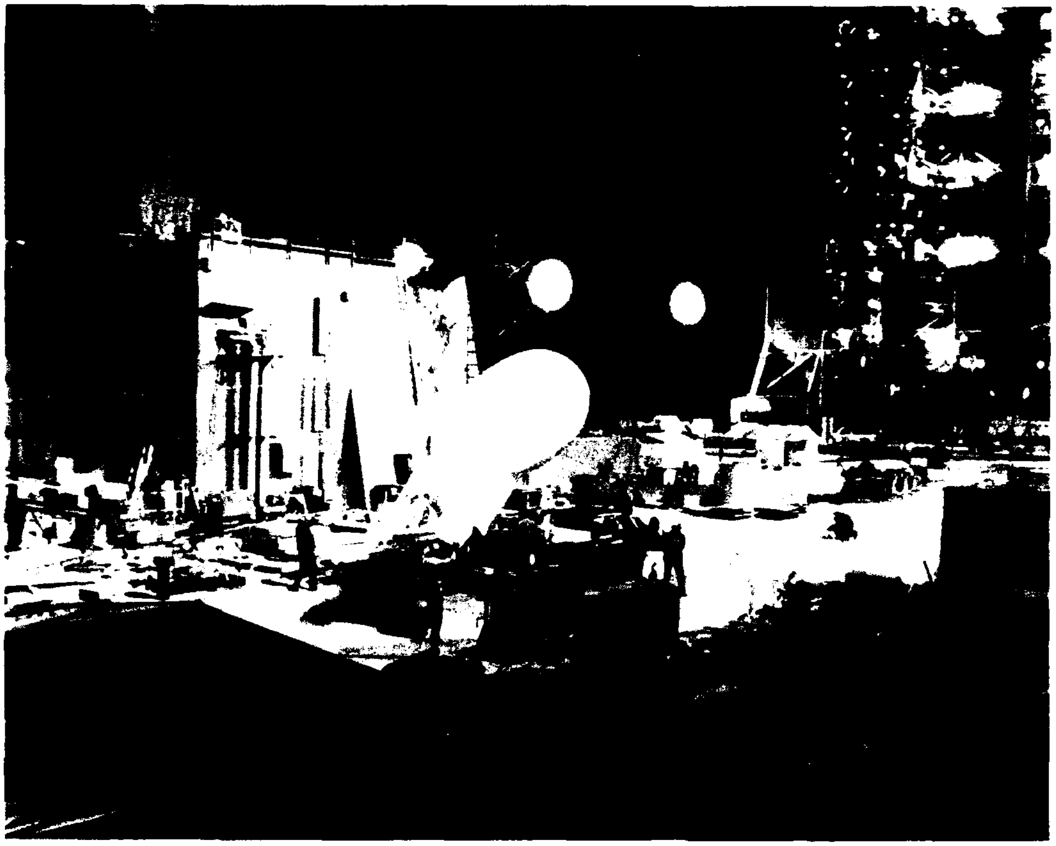


Preparing to Measure the Vibro-Acoustic Environment at Vandenberg's V-23 Launch Site. (High explosive charges will be suspended from the balloon and detonated at selected altitudes over the launch pad. Seismic and pressure loads on the facility will be measured on the ground with the geokinetic data acquisition system.)

VI EARTH SCIENCES DIVISION

The Earth Sciences Division performs research in seismology, geodynamics, geology, geodesy, and gravity. This research supports the deployment, operation and delivery of Air Force weapons with particular emphasis on strategic systems. Instrumentation is designed and produced to measure geophysical phenomena worldwide at varying scales and accuracy levels to meet specific needs. Field work is conducted whenever and wherever necessary. Instrumentation is mounted on a variety of test beds designed to operate on land, in the air, or in space, and data are collected where the organization's experience and theory suggest the need. Theoretical models of geophysical phenomena are developed and cast into a quantitative form for comparisons with observations. Tested mathematical models of geophysical phenomena are produced in formats that are useful in various applications.

During the reporting period, work has been conducted on automated position and azimuth determination, lunar laser ranging, satellite interferometry with Global Positioning System (GPS) satellites, very long baseline interferometry, absolute gravimetry, high-altitude gravimetry, gravity gradiometry, and geopotential modeling. Effort has also been applied in crustal motion research, the development of tiltmeter technology for Air Force geophysical applications, vibro-acoustic forecasts for the Air Force Space Transportation System (Space Shuttle) facilities, low-frequency transmission effects from jet engine suppressors (Hush House), and the determination of detailed mechanics of the motion environment of portions

of the American southwest of particular interest to the Air Force.

GEODESY AND GRAVITY

Geodesy is concerned with the size, shape, and mass distribution of the earth, and its orientation in inertial space. Geodetic information is a necessary foundation for the accurate determination of positions, distances, and directions for launch sites, tracking sensors, and targets. The geodetic and gravimetric parameters for the earth and geodetic information for positioning not only form the structural framework for mapping, charting and navigational aids, but are also direct data inputs for missile inertial guidance systems. Current geodetic information is inadequate to meet the requirements of future Air Force weapon systems.

The Geodesy and Gravity Branch conducts continuing research and development programs in geometric geodesy and in physical geodesy (or gravity). These programs are directed toward improving the fundamental knowledge of the earth's size, shape and gravity field and the techniques used for determining position, distance, and direction on the earth's surface in terrestrial and inertial three-dimensional coordinate systems.

In programs such as satellite altimetry, gravity gradiometry and very long baseline interferometry, AFGL cooperates with the Defense Mapping Agency, the Navy, the National Aeronautics and Space Administration, the National Oceanic and Atmospheric Administration, as well as other civilian agencies and universities.

Very Long Baseline Interferometry (VLBI): A promising technique being actively pursued by the Geodesy and Gravity Branch is very long baseline interferometry (VLBI). In this technique, a plane wave front from a distant quasar source arrives at two radio observatories at different times, depending on the direction of the source, the orientation of the earth, and the locations of the observatories on the earth. The VLBI technique can precisely determine the time difference by the cross correlation of the signals recorded at the two observatories. As the earth rotates, the time difference changes, and the VLBI data can be used to determine earth rotation and irregularities, polar motion, source directions and very precise intercontinental distances between, and relative positions of, the radio observatories. Most recently, an AFGL sponsored study has produced observations of nutations, or oscillations, of the earth's rotational axis at periods of 9.1 to 365.3 days. Accurate measurement of the magnitude of these nutations is important in precise geodesy, as it contributes to latitude and longitude accuracy, as well as length-of-day accuracy.

Laser Ranging: A world-wide network of earth-based laser-ranging systems is making accurate distance measurements from the earth to reflector packages placed on the moon and on high altitude geodetic satellites. Scientists from AFGL and its contractors have analyzed these data using the Planetary Ephemeris Program developed by the Massachusetts Institute of Technology under contract to AFGL and other DoD agencies. Although research has concentrated on studying earth rotation and polar motion, the analyses have led to significant advances in the fields of geodesy, geophysics, celestial mechanics and fundamental physics. This study combines data from lunar laser ranging, very long baseline interferometry, and satellite laser ranging into a single series for measuring pole position and represents the first example of a continuous measure of variations in the earth's axial rotation. The typical formal uncertainties are 0.005 arcsec (approximately 20 cm on the earth's surface) for the latitude variation and 0.5 msec (during which time the earth rotates approximately 20 cm at the latitude of the observatory) for UTO (Universal Time, uncorrected for polar motion).

When corrected for polar motion, the values (designated UT1) may be used to estimate changes in the length of the day. Changes in length-of-day values determined from lunar laser-ranging data have been compared with those inferred, using the principle of conservation of angular momentum, from determinations of the angular momentum of the global atmosphere computed from analyses of zonal winds. Both agree closely in identifying an oscillation in the length of the day of about 0.2 msec, with a cycle approximately 50 days' long.

Satellite Radio Interferometry: AFGL is continuing development of a geodetic technique for position and distance determination based on radio interferometric observations of the L-band signals transmitted by the earth orbiting NAVSTAR satellites of the Global Positioning System (GPS), as shown in the figure. In satellite radio interferometry, signal phases are received simultaneously at two sites. The three Cartesian components of the baseline extending between the two receivers are determined by analyzing data derived from simultaneous observations at the two sites. To exploit this technique, AFGL is developing MITES (Miniature Interferometric Terminal for Earth Surveying), an inexpensive, portable system for surveying over long or short baselines using NAVSTAR carrier signals. The goal of this research is to demonstrate by actual field measurements that the components of a baseline vector can be determined with an accuracy approaching 3 parts in 10 million.

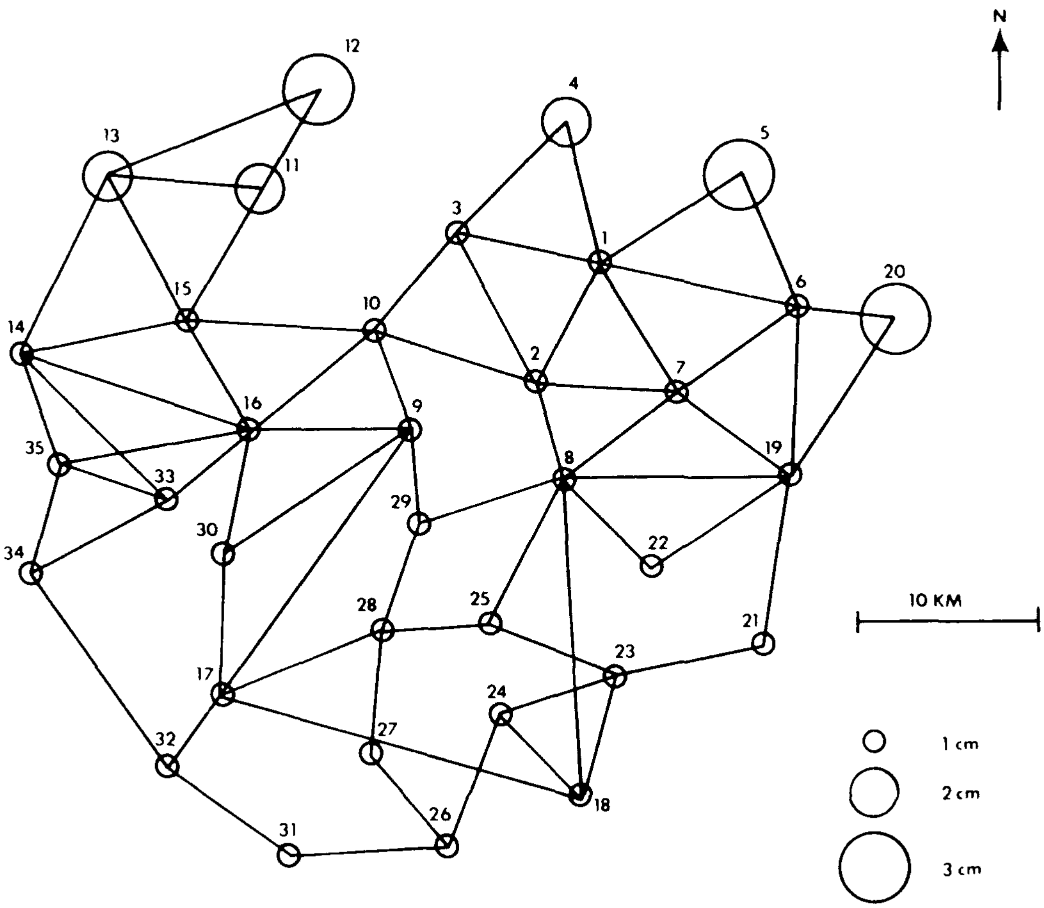
Precise Positioning Using GPS Satellites.

To demonstrate the precision of this technique, observations were made on a multistation geodetic network in West Germany (see the figure). This was a test of radio-interferometric observations of the Global Positioning System (GPS) satellites to establish a three-dimensional, multistation, geodetic control network. The reproducibility of interferometric determinations of individual baseline vectors and the three dimensional vector closure of subnetworks and the whole network were determined by GPS interferometry within about 1 part per million (ppm) in both horizontal coordinates and about 1.6 ppm in the vertical.

As an external test of horizontal accuracy, baseline lengths were compared with electro-optical distance measurements. The vertical accuracy was tested by means of spirit leveling and gravimetry. The differences between the interferometric and the independent determinations are consistent with the uncertainties of the latter. Interferometry with GPS is by far the most efficient method of establishing geodetic control on local and regional scales. This is already true, even though the constellation of satellites is incomplete. The accuracy of regional control by GPS should improve to about 0.1 ppm when interferometry is also used to determine the satellite orbits.

Three AFGL dual-frequency interferometry receivers are operating at radio astronomy observatories in Westford, Massachusetts, Richmond, Florida, and Fort Davis, Texas, to take advantage of the superior hydrogen-maser frequency standards used in VLBI observations. A large amount of data have been collected on the Westford - Richmond baseline. These data will permit a reliable comparison of VLBI and satellite interferometry as baseline-determining techniques.

With the use of dual-band receivers and more accurate determination of the GPS



West German Geodetic Network Measured with MITES-type Receivers. (Uncertainties of station positions were determined from simultaneous adjustment of 67 baseline vectors.)

orbits by interferometry, and as the GPS constellation is expanded, the uncertainty of baseline determination will be reduced by an order of magnitude or more, to the level of 0.1 ppm, or below. This achievement will make GPS interferometry a logical choice for the task of monitoring crustal motions in the many geophysically interesting areas. For the majority of geodetic and geodynamic applications, however, in which 1-ppm accuracy is adequate, GPS interferometry is already clearly the best method of establishing three-dimensional control.

Advanced Techniques for Gravity Field Modeling: Gravity modeling is done either on a global or a local basis. Global models may take the form of a collection of mass points distributed at various depths around a sphere or as finite series of spherical harmonic functions. The latter have been developed from gravity data, satellite altimetry, and other data to degree and order 180, which corresponds to a resolution of approximately 110 km. The computational effort required to compute the coefficients of such a long series is evident from the number of independent and globally distributed data that must be included in the calculation, at least 32,400 (equal to the number of coefficients) and usually twice that for increased accuracy. Longer series to degree and order 300 (90,000 coefficients) are also being de-

veloped with corresponding software of increased efficiency. Once a set of coefficients has been calculated, it determines not only the gravity potential, but also the three components of the gravity vector and all its gradients. Optimal estimation of these coefficients, where all estimation errors are minimized, involves even more computations, and numerical techniques were devised to lessen the computational load while maintaining a good approximation to optimality. The problem of the possible divergence of the spherical harmonic series near the earth's surface was addressed with alternative expansions on the basis of a nonspherical earth model.

As with spherical harmonic series, the point-mass modeling approach requires the employment of sophisticated techniques because a large number of unknowns has to be determined from a large amount of data. A method was studied which transforms the problem into the frequency domain, where linear systems of equations of lower order can be solved.

Local gravity modeling attempts to describe the local gravity field with a resolution as small as 5 km over areas as large as 10,000 km^2. A significant effort to understand the relationship and influence of topographic density anomalies on gravity-field determination both at the earth's surface and at low altitudes has led to a number of important results. Topographic information does in fact contribute substantially to short-wave-length gravity determination and if removed from the estimation problem, enhances statistical longer-wavelength estimation. The topographic effect was also studied for the upward continuation of gravity data, with the result that it does play a significant role. Corresponding software was efficiently developed to process the voluminous topographic data sets that are generally available in most regions of the world. Additional studies concern the statistical relationship between gravity and density distributions and corresponding geophysical inversion methods.

A study of the feasibility of a world-wide vertical datum was initiated with the intent of determining what data would be necessary to achieve such a datum and what the presently attainable accuracy would be. A vertical datum is the reference surface for topographic elevations and is generally tied to mean sea level. However, mean sea level varies because of currents, atmospheric conditions, tides, and other geophysical phenomena. Thus, all vertical datums around the globe are essentially independent and disjoint. A unified global vertical datum is desirable for many DoD applications, and also from a purely geodetic point of view, but constructing it means abandoning mean sea level as the defining surface. Instead, a gravity potential isosurface (constant potential) would serve as the reference of all heights around the world. The vertical datum connection between major continents would be established through geocentric positions of satellite laser tracking stations by estimating the geopotential at these stations, and also by utilizing the geopotential differences between regional stations obtained through leveling networks. With available gravity and position data, such connections are estimated to be accurate to about one-half meter, which is not sufficient for many applications. Therefore, better data in quantity must be obtained if a useful global vertical datum is to be achieved.

Automated Astronomic Position Determination: Geodesy is concerned not only with positioning but also with the orientation of a site in inertial space. The conventional reference standards for inertial orientation are stars. The positional coordinates derived from the inertial systems are known as astronomic latitude, longitude and azimuth. Other inertial reference standards besides the stars exist (the lunar orbit and gyroscopes, for instance), but currently the stars are the best and most widely used inertial reference standards available to geodesists. Studies have also shown that the human

observer can be the largest error source in astronomic position determination. Therefore, AFGL's astronomic position determining and azimuth transferring and monitoring experiments deal with various phases of automating one or more of the components involved in this very specialized type of position determination.

The AFGL research and development program in automated positioning includes: (1) Determination of azimuth, or a reference direction such as the orientation of the earth's rotation axis; (2) Automation of astronomic position determination; (3) Development of a method to measure refraction through the atmosphere at a survey site.

As part of a program to automate the astronomic positioning process, AFGL, the Defense Mapping Agency and the University of Maryland cooperated in development of an automatic eyepiece equipped with a photosensor to replace the visual eyepiece on a T-4 geodetic theodolite. This photoelectric "camera" head automatically records the passages of stars across the field of view of a coded system of photosensors. Tests of the device produced angular differences between star pairs well within human visual capabilities. The prototype was delivered to the Defense Mapping Agency and formed the basis for a preoperational model which has recently been tested with excellent results.

Another AFGL program is the precise determination of astronomic latitude and azimuth using laser gyros. The use of lasers in the measurement of inertial rotation has been receiving considerable attention for more than a decade. The ring laser gyro supports two counter-propagating light paths that share a common cavity as well as a common amplifier. In the presence of rotation with respect to inertial space perpendicular to the plane of the cavity, the degeneracy in the frequencies of the two oscillators is removed, since, as Sagnac predicted, the optical lengths of the clockwise and counterclockwise paths around the ring are no longer equal.

Recently, the F. J. Seiler Laboratory (U. S. Air Force Academy) has been investigating a new method of measuring inertial rotation, also based on the Sagnac effect, which promises to be free from the major problems normally encountered in the ring laser gyroscope. The new concept is based on a passive ring Fabry-Perot interferometer (with an external laser) that measures the difference between the clockwise and counterclockwise lengths of the cavity caused by inertial rotation. Because the reference cavity is passive, all the problems normally associated with the gain medium in the conventional ring laser gyroscope are eliminated.

The Seiler Laboratory has constructed a large ring laser, 7.6 m on a side, which has the required large area without the disadvantages of large area multiturn fiber optics laser gyros.

Honeywell, Inc., has completed the analysis of the feasibility of sub arc-second measurement of earth crustal tilt and earth spin axis deviation, in less than one day, using ring laser gyroscopes and tiltmeters. Experimental results show that the axial stability is adequate and that the random drift is low enough and the output resolution is fine enough to perform precision geophysical measurements. As a result of this favorable study, the decision has been made to proceed with the construction of a system that will measure combined polar-axis deviation and earth crustal tilt to within 0.2 sec of arc. This is a north-seeking system and therefore azimuth-determining. It will be configured to provide information for the determination of latitude.

Absolute Gravimetry: The AFGL program in absolute gravity experimentation has produced equipment concepts, methodology and standards accepted by the geodetic community as meeting or exceeding the precision and accuracy requirements for the future.

AFGL has played a major role in the establishment of the absolute gravity calibration line in the United States as well as in cooperative international grav-

imetric comparisons in Europe. Results have been compared with measurements made with the different methods and equipment concepts of gravity meters from Italy, the USSR, France, and other institutions in the United States.

Since the present and foreseeable requirements in absolute gravity have been met, and the program has evolved into field surveys of new gravity stations and remeasurement of existing sites, which is outside the AFGL research mission, support is continuing only in the area of consulting and advising on the development of improved gravimeters.

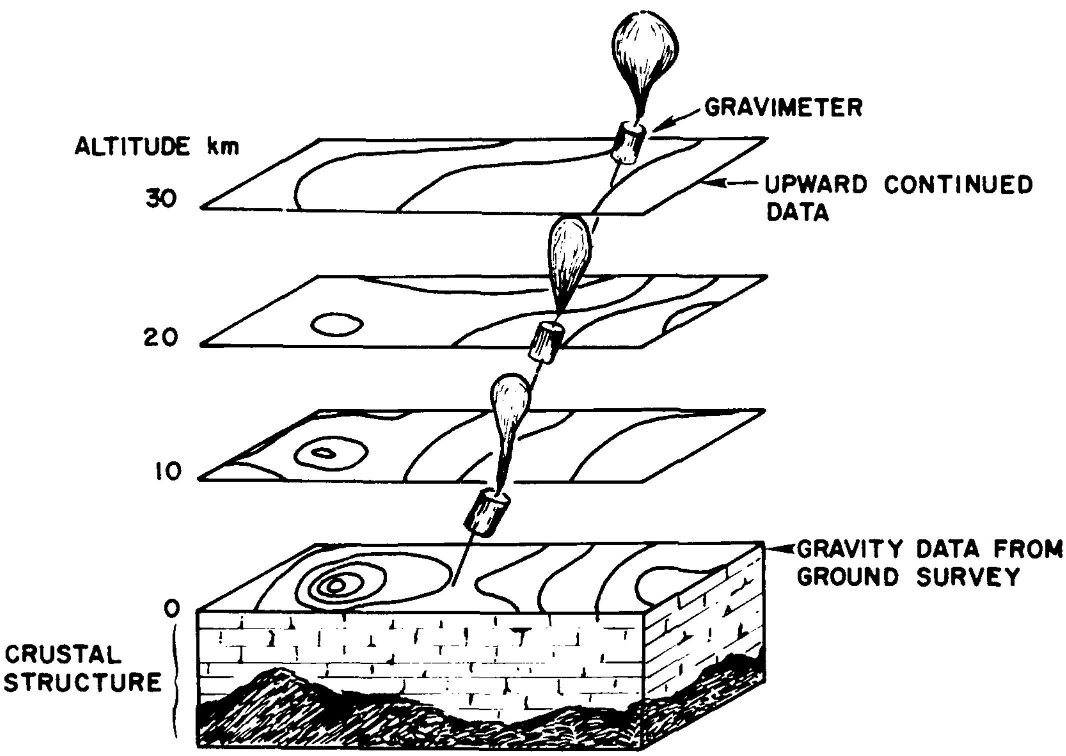
Balloon-Borne, High-Altitude Gravimetry: Gravity field values at high altitudes (e.g., 30 km) are normally estimated from upward continuation of surface measurements, or downward continuation of satellite measurements as computed from orbital perturbations. These techniques are well developed with generally accepted results, but are subject to some limitations. Upward continuation depends upon the quality and distribution of surface data, usually nonuniformly spaced and taken from different surveys. Thus, gaps and uneven spatial distributions may result in inaccurate upward continued estimates. With increasing altitude, short wavelength information from crustal structure is attenuated and not recoverable from downward continuation from satellite altitudes.

Verifying gravity data bases and models requires establishing the validity of the models at locations where measurements have not been made. While such models can currently be effectively tested at ground level, their validation at altitude awaits the development of suitable approaches. The Air Force Geophysics Laboratory is developing a program to verify gravity model estimates by measuring gravity directly using high-altitude balloons. A gravimeter package suspended beneath a balloon is in a dynamic, and largely unpredictable, environment sensing not only the Earth's gravitational acceleration, but also all accelerations due to the motions of the balloon system. For a specified time interval (e.g., 1 sec) during which a measurement is made, the variation in balloon accelerations is expected to be significantly greater than the variation expected in the Earth's field (see the figure). Therefore, additional instrumentation is required to measure as many balloon motions as possible, such as rotation, bobbing, and swaying. As all such ancillary sensors are dependent on the local inertial frame, gravitational accelerations cannot be separated from vertical balloon accelerations without additional data acquired independently of the frame of reference of the balloon. These independent data are extracted from balloon tracking, which must accomplish three objectives: (1) measure the gravimeter package accelerations (especially the vertical) referred to a ground-based coordinate system, (2) measure velocity for estimation of the Eötvös effect, and (3) measure gravimeter position, which is used as an input to the gravity model. Combining balloon data with tracking data allows for the separation of balloon-induced accelerations from gravitational accelerations.

The long-term goal is to determine gravity to 1 mgal (10^{-3} cm/sec^2 - about 1 ppm). This goal can be achieved by determining vertical accelerations to 1 mgal, east velocity to 5 cm/sec, and position to 3 m in all three orthogonal coordinates. We are planning to incorporate Global Positioning System (GPS) satellite tracking to provide uniform and accurate tracking anywhere on Earth. A separate investigation is now underway to determine the capability of GPS satellites to track a moving antenna relative to a ground-based, fixed antenna. We plan to extend the testing to measure the differential range between the balloon gondola and one or two ground stations on the next flight (see the figure).

Gravity Gradiometer: All Air Force inertial navigation systems (INS) rely on a model of the earth's gravity field for precise point- to-point navigation. While satellite-based measurements provide long wavelength information about the

BALLOON GRAVITY



Upward Continued Gravity Model as a Function of Measured Gravity.

Balloonborne High Altitude Gravity Measurement Package.

earth's gravity field, only near-earth measurements can accurately determine the short wavelength features. Until now, the collection of these types of data has been labor intensive and slow. In fact, in geographically harsh areas, conventional gravity survey methods are nearly impossible to implement and suffer from lack of geodetic control and, therefore, accuracy. As the accuracy of INS has increased, so has the demand for large amounts of short wavelength gravity data. This demand accelerated the search for an automated mobile gravity-data acquisition system.

AFGL has explored the possibility of measuring gravity from moving platforms, such as aircraft, since the 1950's. Early results indicated that using standard gravimeters would present great dif-

ficulties in separating the acceleration due to gravity from other accelerations induced by aircraft motion. In the early 1960's, a new concept arose that called for measurements of gravity gradients rather than gravity (see the figure).

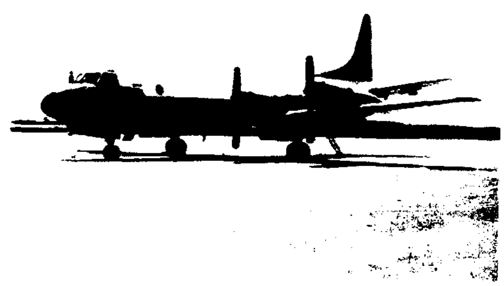
Gravity Gradiometer Survey System.

The measurement of gravity gradients is more suited to moving environments for several reasons. First, it resolves the problem of the fundamental inseparability of inertial and gravitational accelerations that has hampered moving-base measurements and gravity. From the relationship between accelerations in inertial and noninertial reference frames, it is easy to show that an inertially stabilized gradient measuring system yields data that are independent of linear inertial accelerations. Second, a gradiometer system comprises a number of (differently oriented) gradient sensors sufficient for the determination of the five independent elements of the gravity gradient tensor. This permits the direct calculation of not only the vertical gravity component, but also the deflection of the vertical (DOV); i.e., the full gravity vector is obtained. Third, because the gradiometer is an instrument designed to sense the short-wavelength variations of the earth's gravity field in the form of gradients, it provides the type of data necessary for accurate interpolation of gravity between survey tracks.

Full-scale development of a land and an airborne Gravity Gradiometer Survey System (GGSS) is now underway. A P-3A aircraft is being modified to accept the GGSS equipment (see the figure). An interface is being designed to connect the GGSS computer system to the autopilot in the aircraft. Survey pattern information input to the computer at the start of a mission will be used together with real time navigation data from a GPS receiver to track the aircraft through the survey. The central computer will control the operation of the total GGSS. It will process the navigation data from a GPS receiver, perform the control of the survey pattern and record data on magnetic tape from the various sensors.

A critical aspect of an airborne gradiometry system is that the data coverage over the survey area must be sufficiently dense. The expected estimation accuracies for an ideal survey at 600 m altitude and 5 km track spacing is 1 mgal in magnitude and 0.2 arcsec for deflections over a large area. Tracks are assumed to run in two orthogonal directions. The error of estimation is quite sensitive to track spacing, however, and the accuracy goal cannot be achieved with unidirectional tracks.

The test program will take place in late 1986. It will be divided into two parts: land and airborne. The land test will evaluate the GGSS repeatability and its ability to transfer both gravity and DOV between



P-3 Aircraft to House GGSS system.

known astro-geodetic stations. The airborne test will assess how well the gradiometer can reproduce very accurate ground truth data over a large area (300 km by 300 km).

GEOKINETICS

In recent years the technological advancements within a wide range of Air Force systems have made their operational performance more susceptible to their earth motion (geokinetic) environments. Inertial guidance instrumentation is a typical example. Each generation of gyros and accelerometers developed for use in guidance systems exceeds the sensitivity of the previous generation by an order of magnitude or more. Unfortunately, this enhancement in performance increases their sensitivity to geokinetic effects and advances the potential for errors caused by the motion environment in which they must operate.

Structures may also be susceptible to motion effects, not only on their integrity in strong motion environments (missile launches) but also on any motion-sensitive equipment and systems they contain. The response of these structures to disrupting forced vibrational wave fields must be established and compensation made within the adverse frequency bands to preserve the operating integrity of the facility and the system.

Other areas where geokinetic effects contribute to degrading optimum capabilities and performance are: (1) seismic discrimination: for determining source characteristics generated by earthquakes and explosions, or vehicular and aircraft activity whose seismic signatures are masked or colored by such factors as the transmission path and environmental noise; (2) seismic communication: for preservation of the intelligence portion of the generated ground signal that is predicated on the intensity of the local earth background-noise environment and transmission path; (3) seismic detection: for monitoring covert activities and maintaining physical security; and (4) Environmental Impact Statements: for establishing data base criteria for engineering and legal concerns.

To suppress or compensate for geokinetic effects, the ground transmission attributes must be known. Since these attributes are dependent on the areal geology, the transmission properties of the environment must be fully assessed. The objectives, then, of the geokinetic research and development conducted by the Earth Sciences Division are threefold: (1) to develop methods for rapidly assessing the environmental seismic propagation attributes of a local site, (2) to forecast site ground motion responses, and (3) to recommend methods for suppressing or compensating for these motions.

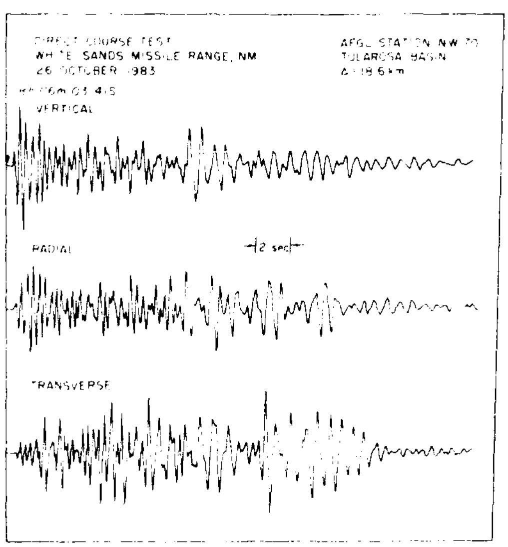
Geodynamics: Geology, tectonics, and seismology are studied to predict the spatial and temporal properties of motions of the earth's crust over a wide range of frequencies. Specific efforts include measurement and interpretation of long-period, secular deformation and realistic modeling of the effects of seismic motion on Air Force systems and structures.

An array of borehole tiltmeters has been installed at Yellowstone National Park, Wyoming, in a program to detect tidal admittance anomalies caused by the volcanic caldera and to search for possible earthquake precursors. Also, a pair of tiltmeters has been emplaced in 50 m boreholes in the La Malbaie seismic region near Charlevoix, Quebec, to detect theoretically predicted changes in the local response to earth tides as rocks are stressed toward their fracture strengths.

In a cooperative program with the U.S. Geological Survey, NASA, and a number of universities, AFGL operated a biaxial tiltmeter at the University of California's Pinon Flat Geophysical Observatory near the San Andreas fault zone northeast of San Diego. The responses of a number of diverse instruments, including tilt, strain and stress meters, and seismometers, operating in an active tectonic area, have been compared.

The Solid Earth Geophysics Branch conducts an ongoing research program aimed at predicting the level, frequency content, and duration of seismic ground motions caused by earthquakes and explosions. Previous work has shown that complex geology at a facility site affects seismic wave propagation and surficial ground motion. These effects cannot be adequately represented using simple assumptions such as plane layering, since the effects include complications like focusing, scattering and wave conversion. Theoretical modeling includes such techniques as three-dimensional ray tracing, finite element, boundary integral equation, and Kirchhoff methods, as well as standard mode and ray theory computations.

Field studies have focused on providing data to test the theoretical calculations as well as measurements of earth properties. A seismogram recorded during the DNA-sponsored DIRECT COURSE high-explosive test at White Sands, New Mexico, exhibits strong transverse motion unexpected from an air blast (see the figure). Evidently, wave propagation through an asymmetric bedrock ridge caused energy to be scattered into the transverse component.



White Sands HE Test where Anomalous Transverse Ground Motion is Evident.

A joint experiment with the Air Force Weapons Laboratory measured scattering from a buried bedrock ridge at Yuma Proving Ground, Arizona. The AFGL seismometers were installed in a tight array (approximately 3000 ft long) to record a 600,000 lb high explosive source. A strong amplitude gradient coincided with the basement ridge, independently discovered using gravity measurements.

Ultrasonic models of a typical western Basin and Range Valley provide another controlled test for the mathematical models. These laboratory experiments also allow insight into the physics of wave conversions since structural models can be simplified and controlled. For example, Rayleigh surface-wave amplitudes are diminished in crossing a model mountain range, while the duration is increased compared to waves that propagate within a homogeneous structure.

Seismo-Acoustic Studies: During 1983 and 1984 AFGL continued to provide support to the Space Division Space Transportation System (STS) Program requirements for ensuring the structural integrity of major ground support facilities and the survivablity of motion sensitive equipment in the facilities during an STS launch at Vandenberg AFB. This support effort was divided into two elements. First, AFGL monitored launches of the STS at Kennedy Space Center to provide data for the evaluation of an STS launch acoustic-emissions model. Second, a series of explosive tests were monitored at the launch complex (V23) at Vandenberg AFB to evaluate the site-peculiar vibration and acoustic responses of V23 facilities to acoustic loads.

The AFGL Geokinetic Data Acquisition System (GDAS) was used at Kennedy Space Center to monitor the STS-8 launch in August, 1983, and the STS 41-B launch in February, 1984. The primary goal of these studies was to explain the lack of axial symmetry in the acoustic emissions of the STS launch that was observed by AFGL during the launch of STS-5 (November, 1982) at Kennedy. Just prior

to the launch of STS-8 the GDAS system was knocked out by a close lightning strike (see the figure). However, observations at STS 41-B showed that the azimuthal variation was primarily the result of excess attenuation along certain azimuths caused by the vapor cloud of the water noise suppression system used at Kennedy. Further analysis of the data obtained during STS-5 and STS 41-B demonstrated that, for the frequency range of interest, STS acoustic emissions in the range of 500 to 1000 ft from the launch mount could be adequately modeled as an equivalent point source located in the rocket plume and substantially below the rocket exhaust ports.

Lightning Strike During Launch Countdown for the KSC STS-8 Shuttle Launch. (The strike did not affect the launch but it did prevent AFGL from collecting vibro-acoustic launch environment measurements.)

During February and April, 1984, a series of explosive tests were conducted at Vandenberg AFB V23 and the Explosive Ordinance Detachment (EOD) test range to establish the response characteristics of major ground support structures to acoustic loads. During the period, GDAS was deployed in the Payload Preparation Room, the Administrative Building and the Payload Changeout Room at V23. Vibration and pressure data were collected at a limited number of locations in, or on, these structures for a series of small detonations at different elevations over the V23 launch mount. A more complete study, intended for April, 1984, was cancelled by the Shuttle Activation Task Force (SATAF) due to conflicts with the V23 construction schedule.

The site response data collected at V23 and the STS acoustic emissions model based on Kennedy data were combined to provide forecasts of the vibro-acoustic environment at V23 during an STS launch. The major conclusions of this study were: (1) There exists a high probability that the Payload Preparation Room and the Payload Changeout Room will pound during an STS launch. (2) Motion levels in certain locations within the Administrative Building approach levels of concern for the survivability of sensitive equipment. (3) The pressure loads reflected back on the STS itself could be as much as 15db higher than those experienced at Kennedy.

During 1983 AFGL also continued its support of the Tactical Air Command by analysis of the effects of sonic booms on ancient Indian monuments and structures located under the Valentine, Texas, Military Operations area. AFGL conducted a theoretical study to demonstrate that these cave dwellings and petroglyph bites were probably more at risk due to earthquake generated vibrations and natural environmental degradation than to sonic-boom induced motions.

A seismic hazard study was also conducted for the states of Nevada and New Mexico during 1983. This study highlighted earthquake-risk areas and their estimated frequency of earthquake occurrence in this region. Studies of this type are necessary to assist Air Force planners in locating motion-sensitive installations.

During 1984 Ballistic Missile Office objectives were supported by theoretical studies for the MX Deep Basing Mode. A seismic ray-tracing code developed for AFGL was used to study the seismic motions which could impact missile operations for silos located inside mountains. In 1984, Logistics Command asked AFGL to examine vibration problems associated with the acoustic emissions of jet engine ground run-up test cells (Hush House). Preliminary field work was conducted at Luke AFB during September and October, 1984. The GDAS system was used to monitor the "free-field" acoustic emissions of a Hush House and the response of a building to these emissions. In addition, explosives were detonated near the Hush House to determine the impulse response of the monitored structure. As at Vandenberg's V23, the response and "free-field" emissions will be used to predict the induced motions in the monitored building. The ultimate goal of this work is to provide Logistics Command with a method for forecasting the impact on nearby structures of siting a Hush House.

Studies were also conducted with the goal of increasing the accuracy of large earthquake-motion forecasts for specific sites by improved analysis techniques. Areas being studied include improving the estimation quality of static to dynamic elastic-moduli variations and the use of small earthquake motions as Green's functions for larger events.

AFGL is fabricating a Vibro-Acoustic Measurement System (VAMS) designed by AFGL to monitor the first three shuttle launches from Vandenberg AFB. The VAMS is an easily reconfigurable, flexible, distributed computer network designed for monitoring environmental motions. The heart of the system is a master control unit, a super fast microprocessor to centrally manage the network and peripheral processors, as well as to continually record data. Closely coupled to the master is a standard microcomputer for serial code execution, and an array processor for the massively parallel data processing required in digital signal processing. Five slave units are coupled to the master. Each slave consists of a microcomputer, nonvolatile memory for data storage, an analog-to-digital converter, and an analog front end. The analog characteristics of the slaves are alterable, many in software requiring only fractions of a second, and others requiring wires to be jumpered, taking possibly several hours. Each slave can handle sixteen sensors, and with five slaves the system capacity is eighty channels.

Currently, the VAMS is capable of recording and analyzing seismic and/or pressure signals with a maximum frequency of interest at 50 Hz. Accuracy is better than 0.5 percent for pressure in the range from 0 to 5 psid and 0 to 20 psia. Sensitivity of the seismometers to motion is better than 2 x 10^{-6} cm/sec. This is well below the average ground noise present.

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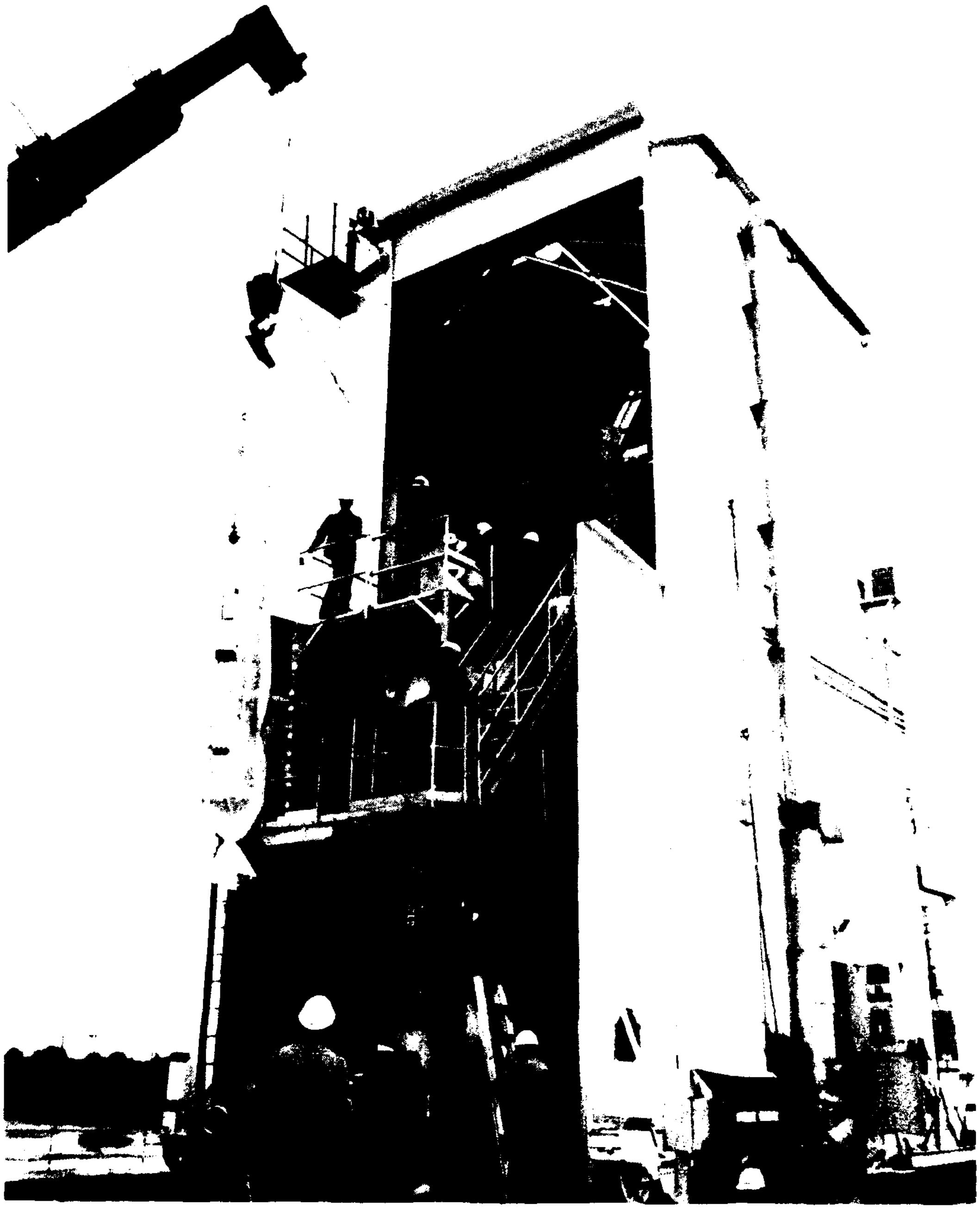


Launch Preparations for Earth Limb Clutter (ELC) Experiment to Measure Earth Limb Radiation in the Upper Atmosphere. (The payload was 203 in. long and weighed approximately 1315 lb.)

VII OPTICAL PHYSICS DIVISION

The optical and infrared properties of the natural and man-made environment and radiation sources are the focus of research in the Optical Physics Division. These properties include atmospheric transmission, infrared backgrounds, target signatures, and the development of new optical and spectroscopic techniques. Infrared backgrounds comprise the earth, atmosphere, horizon or earthlimb, celestial sky and zodiacal emission. The research encompasses field measurements, laboratory studies, and theoretical studies and analyses.

The goal of the research program is to develop "tools" that can be used directly in the design and operation of Air Force and DoD systems. These tools include various data bases, models and computer codes such as the LOWTRAN atmospheric transmission and HITRAN laser transmission computer codes, the AFGL IR Star Atlas, and LWIR Earth Limb Model.

The portion of the electromagnetic spectrum studied extends from 2,000 Å in the ultraviolet to 1 cm, where the far infrared blends into the microwave radio spectrum. The research in the Division includes studies of: the visible and near visible properties of the atmosphere, where aerosol and molecular scattering is the predominant mechanism of attenuation; the infrared properties of the atmosphere, generally where thermal equilibrium usually prevails; and the infrared properties of exoatmospheric sources — stars, nebulae, and zodiacal dust. Improved techniques for spectroscopic, lidar and scattering measurements are also developed.

A major area of investigation by the Division concerns atmospheric attenuation, or transmission and scattering of radiation by the atmosphere, including laser beams. Atmospheric molecules absorb optical and infrared radiation selectively at discrete wavelengths. Extensive computer programs have been developed which make use of the vast collection of spectroscopic data for molecules (*AFGL Atmospheric Absorption Line Parameters Compilation*) and which permit the calculation of this transmission, both for laser beams and the emission and transmission of radiation from hot gases and plumes. Detailed atmospheric absorption curves and tables for high resolution and laser transmission are available. The well-known LOWTRAN atmospheric transmission computer code is used for determining the low-resolution (approximately 20 wave-numbers) transmission of the atmosphere for a wide range of tactical weapon-delivery problems under various meteorological conditions. The codes have been designated as the standard atmospheric codes for both the Department of Defense, as part of the DoD transmission program, and for the international research community, as part of the Technical Coordination Program and the International Radiation Commission.

Scattering by aerosols and molecules in the atmosphere also contributes both to attenuation and to reduction in the contrast of a target seen through the atmosphere. A mobile facility to obtain aerosol and transmission data for the lower atmosphere at various locations, especially under adverse weather conditions, has been developed and deployed for various field-measurement programs. This facility incorporated newly developed instruments to measure visible and infrared transmission and scattering. The results of these measurements and models are applied to target acquisition and detection problems as, for example, a Tactical Decision Aid (TDA) to describe the impact of the natural environment on air-to-ground IR-guided weapon systems (maximum lock-on range), and also to laser propagation studies.

Turbulence in the atmosphere leads to fluctuations in the brightness, coherence and direction of a laser beam propagating through that atmosphere. Efforts are under way to measure and model the altitude and temporal variations in the index of refraction of the air, the most important parameter in determining these effects.

A powerful technique for remotely determining the optical and meteorological parameters and composition of the atmosphere from the ground or space is through the use of a lidar, which measures the transit time and intensity of the light scattered back from a laser pulse at one or more wavelengths. Different lidar techniques will be exploited, including molecular and aerosol scattering, resonance fluorescence, Raman, and DIAL (Differential Absorption Lidar).

Similarly, infrared backgrounds against which a target must be located are a major concern of the Division efforts. Such emissions from the atmosphere or celestial sky represent interfering background noise superimposed on the optical/IR target signatures that a surveillance system may be trying to detect. An inseparable part of these measurements is the development of very sensitive, advanced cryogenically cooled infrared sensors and spectrometers. A high-resolution cryogenically cooled Fourier interferometer has been flown on a balloon to observe infrared atmospheric emission. The infrared emission of the lower atmosphere can be calculated from computer programs such as those discussed above. The IR emission from the upper atmosphere has been measured by using a balloonborne cryogenically cooled interferometer spectrometer, and emission from the earth limb was detected by a rocketborne cryogenic LWIR sensor.

A satellite or rocketborne infrared system looking away from the atmosphere will still see the celestial sky as a background. Consequently, the Division has carried out a rocket program to map the

celestial sky, as well as zodiacal emission in the infrared. The design of a meter class infrared astronomical telescope and sensor cooled by liquid helium is presently under way for use in space. It is called LAIRTS (Large Aperture Infrared Telescope System).

ATMOSPHERIC TRANSMISSION

The atmospheric transmission of electromagnetic radiation in the ultraviolet, visible, infrared and even in the millimeter wave region is affected by molecular absorption and scattering and by extinction from particulates (dust, haze, fog, rain) in the atmosphere. The relative importance of these different attenuation processes depends on the wavelength of the radiation and on the atmospheric conditions.

In a cloud (fog)-free atmosphere, molecular absorption dominates the infrared and millimeter regions of the spectrum, whereas aerosol extinction dominates the visible part of the spectrum. This domination is not complete, however, and a full understanding of atmospheric propagation requires that we deal with the appropriate molecular and aerosol effects at all wavelengths. Molecular absorption is highly wavelength-dependent, whereas aerosol extinction varies much less with wavelength. In the infrared, molecular absorption tends to determine the "windows" within which atmospheric propagation is possible, whereas the transparency within these windows tends to be determined by the molecular "continuum" and aerosol effects. As a result, aerosol and cloud attenuation can be the critical factors not only for visible wavelengths but also for infrared radiation in the window regions.

Aerosol and cloud-drop attenuation can affect radiation propagation in several ways. Particulate scattering and absorption along with molecular attenuation reduce the intensity of a beam of radiation as it travels along an atmospheric path and thereby become factors in determining beam transmittance. For many applications, such as laser beam propagation, we are not only concerned with the extinction loss in a beam of radiation but also with the temporal and spatial intensity variation due to turbulence and angular distribution of the radiation scattered out of the direction of propagation of the direct (incident) beam. One of the most important effects of this scattered radiation is the reduction of contrast in imaging systems at the visual and near infrared wavelengths. The scattered light from the sun forms the background sky radiance against which objects may have to be viewed and detected.

With some exceptions, which are discussed below, the attenuation processes by atmospheric molecules are sufficiently well understood to make accurate predictions of the attenuation effects when the basic atmospheric properties, such as molecular concentrations, air temperature, and pressure, are known.

It is much more difficult to predict accurately the optical properties of particulate matter in the atmosphere, especially those of haze and dust particles. Their optical effects are not only a function of particle concentration, but also of particle size, shape, chemical composition, and physical structure. All these properties are highly variable with weather conditions and location, and they are very difficult to measure. Because of the extreme variability of these properties, it is also very difficult to develop models for the optical/infrared properties of aerosol particles or droplet clouds.

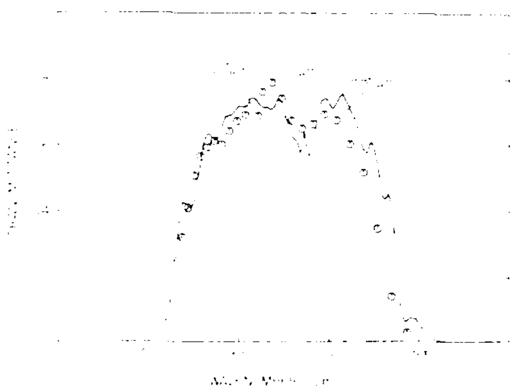
The final goal of this research in the Optical Physics Division has been the development of computer codes which allow an efficient and accurate calculation of these various atmospheric propagation properties for application to Air Force systems and operations.

Atmospheric Transmittance and Background Radiance Models: The atmospheric transmittance and background radiance modeling program focuses on the absorption and scattering properties of the

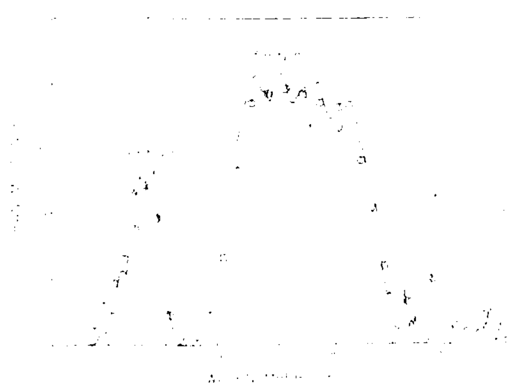
molecular and aerosol constituents of the earth's atmosphere and their effects on radiation propagating through it. In addition, adverse weather effects, such as fogs, clouds, rain, and snow, are included in the program. Two different models for predicting the transmission and radiative properties of the atmosphere for low and high spectral-resolution applications have been developed: LOWTRAN (Low Resolution Transmission) and FASCODE (Fast Atmospheric Signature Code). Both models utilize the same representative model atmospheres, slant path refractive geometry, and continuum absorption models. The models differ in their spectral resolution and spectral range and computational speed of calculation.

The low-resolution model and code, LOWTRAN, predicts atmospheric transmittance, background radiance and scattered solar radiation at a fixed spectral resolution (20 cm^{-1}) and covers the spectral region from the near ultraviolet to the mid-infrared. It provides a simple and computationally rapid means of estimating the atmospheric effects on broadband radiation with an accuracy adequate for most applications (see the figure). The current version of the code, LOWTRAN 6 (AFGL-TR-83-0187), includes improved water-vapor continuum and aerosol models, rain and cirrus cloud models, as well as the contribution to the sky radiance of single scattered solar/lunar radiation.

The second atmospheric propagation model, FASCODE, has been developed for the computation of atmospheric transmittance and radiance using the line-by-line method. This model is applicable to spectral regions from the microwave to the visible. An algorithm for the accelerated convolution of line shape functions (Lorentz, Voigt, Doppler) with spectral line data is used for the high resolution predictions. These calculations are made at a variable sampling interval based on the average spectral line width at all altitudes in the atmosphere (see the figure).

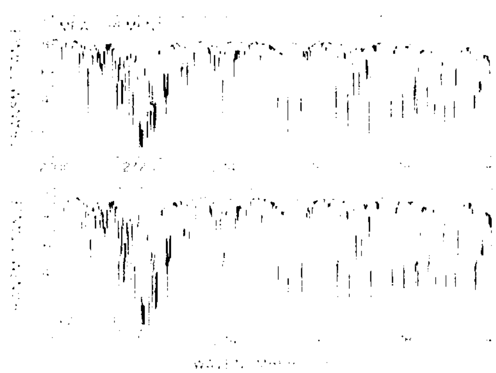


a. 700–1300 cm^{-1} (8–12 μm)



b. 2000–3300 cm^{-1} (3–5 μm)

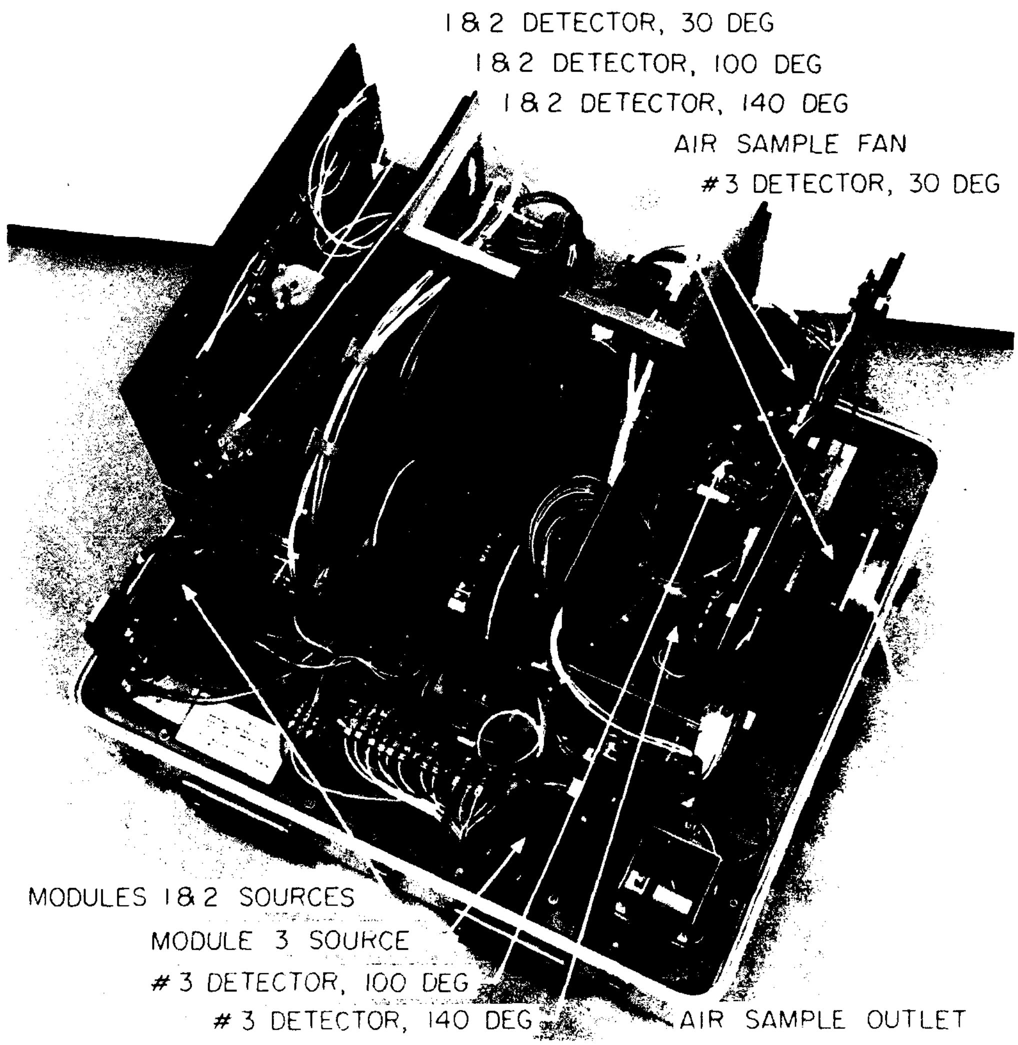
Comparison of the LOWTRAN Model (solid line) with Measurements (symbols) Made by the AF Avionics Laboratory Using a Circular Variable Filter Transmissometer in the Infrared Atmospheric Window Regions. 8 km Path at Wright Patterson AFB, Ohio.



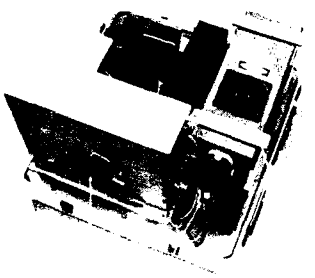
Comparison of FASCODE C (lower curve) with a High Resolution Fourier Transform Spectrometer Measurement (upper curve) by Naval Research Laboratory: 6.4 km Path at White Sands Missile Range, New Mexico.

Options for laser propagation, the computation of weighting functions for remote-sensing applications, and scanning functions are included in this model and computer code. New options to be included in the next update of FASCODE are the treatment of nonlocal thermodynamic equilibrium (NLTE), the addition of the LOWTRAN aerosol models, and the extension of the model atmospheres to 120 km.

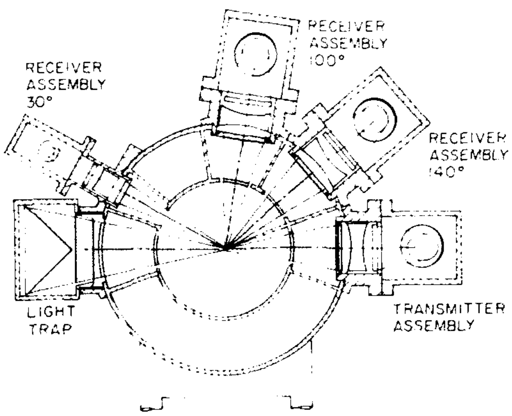
Laboratory and Field Measurements: There is still a serious gap in our knowledge of aerosol optical effects in the planetary boundary layer, the well-mixed layer immediately adjacent to the ground, especially under marginal-to-poor weather conditions: heavy haze, fog and low clouds. To fill this data gap and, at the same time, provide a flexible mechanism for responding to other data needs, a mobile optical infrared laboratory has been developed. This laboratory, the Transportable Optical Atmospheric Data System (TOADS), consists of two instrumented trailers housing numerous instruments controlled by a supervisory processor. Spectral radiance and irradiance measurements in the visible and near infrared (0.35–1.2 μm) are made from one trailer with four grating spectrometers controlled by a minicomputer. This trailer also has a set of standard meteorological sensors. The second



Polar Nephelometer.



10 μm Laser Scattering Unit of Polar Nephelometer.



Schematic Diagram of One Wavelength Module of the Fixed-Angle Four-Wavelength Polar Nephelometer. (*The air sample with the aerosol particles flows perpendicularly to the figure plane.*)

trailer houses two infrared transmissometers, a visible transmissometer, several aerosol probes and aerosol scattering sensors, additional meteorological sensors, and two systems for measuring over vertical paths: a dual frequency lidar and a transmissometer.

The infrared transmissometers can make measurements over paths up to 2 km in the 2–14 μm wavelength region. The aerosol probes are commercially available units which, taken together, will span a size range from 0.002 to 20 μm. Nephelometers for measuring the scattering properties of aerosols include two instruments, one operating in the visible and a dual wavelength (1.06 and 10.6 μm) laser nephelometer.

The lidar, a 1.06/0.53 μm system, has been developed under contract and installed on the top of the trailer in a gimballed mount. It provides relative profiles of aerosol backscattering and derived extinction profiles with excellent time and space resolution, allowing a detailed examination of the vertical aerosol structure in the boundary layer. If the transmissometers are operated in a slant path configuration, they will consist of a specially developed, folded path visible/infrared transmissometer and a retroreflector mounted on a tethered balloon or a tower. They will allow simultaneous determination of the total extinction along a slant path. Data logging, instrument control, and real-time data reduction are accomplished with two microprocessor systems.

A new polar nephelometer, which was built by HSS, Inc., for AFGL, was field-tested during 1984 (see the figures). This instrument measures the scattered light intensity from atmospheric aerosol particles at 30°, 110° and 140° at four different wavelengths between the visible and 10 μm wavelength. This polar nephelometer can be easily transported so that data in different environments can be obtained.

The TOADS system has been used during the past few years to conduct measurements under a variety of atmospheric conditions ranging from clear to rain, fog and snow in support of Air Force or other DoD sensor performance tests. The atmospheric transmission and propagation measurements performed with TOADS not only contributed to a better understanding and modeling capability of these atmospheric effects, but they also made it possible to assess the performance capabilities of operational electro-optical and infrared sensors in different weather conditions.

In addition to particle size and concentration, the aerosol composition is most important for optical and infrared effects of aerosols. There is currently concern about possible modification of infrared absorption bands by the microphysical composition of particles as suggested by "effective media approximations". In short, if particles are spherical and of a

size much smaller than the wavelength, and each particle consists of substances having neighboring absorption bands, considerable band shifts would be expected if the constituent inclusions were fairly large but not if they were very small. Such small inclusions would result if the particle were formed by condensation of vapors or gases in a chimney (in the absence of water vapor condensation), by coagulation of photochemical reaction products as in smog, or by small-nuclei coagulation in general. Large constituent micro-crystals could be made from a spray of mixed-salt solutions, or could be converted from fine constituent particles by temporary water-vapor condensation as in fog. Measurements in the laboratory of absorption bands near 7 μm of smoke aerosols created by chemical reaction of HNO_3 or HCl vapors with ammonia (pure particles for reference), and of premixed acid vapors with ammonia (internally mixed particles having fine inclusions) indeed showed identical absorption bands. Subsequent transformation of the inclusions into larger crystals by raising the relative humidity in the smoke stream and removing the water vapor in a cold trap resulted in a shift of the band of internally mixed particles by 0.1 μm to a shorter wavelength. Of more importance to atmospheric transmittance is the SO_4 band at 9 μm, but the effect of the size of the particle constituents was, in agreement with theory, much smaller.

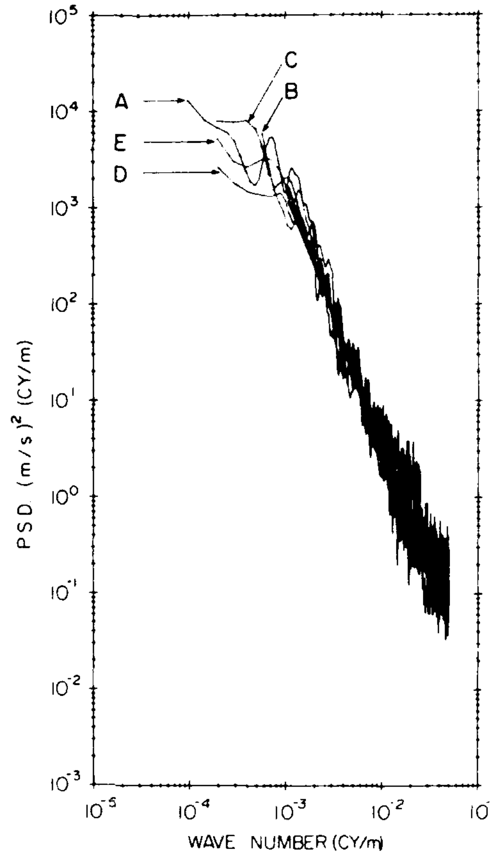
Optical Turbulence: Astronomers have long known that atmospheric turbulence can cause optical propagation effects. The famous "twinkling" of stars is due to such turbulence. When turbulence is at a minimum, astronomers can photograph planets with a minimum of blur because there is less "image dancing." Brightness fluctuations, or scintillations, also diminish when there is low turbulence. The basic cause of the optical effects is the presence of fluctuations in the index of refraction along the optical path.

Increasing importance is being given to atmospheric turbulence effects on optical systems. Ground-based laser systems are especially affected by turbulence. It is thus important to measure turbulence under varied climatological conditions and at various locations to understand the processes which contribute to the phenomenon. To this end, AFGL has conducted experiments at several locations: White Sands Missile Range, New Mexico; Table Mountain, Boulder, Colorado; and Mt. Haleakala, Maui, Hawaii. These experiments provide site-specific characterization of the turbulence. The results have immediate application to ground-based laser systems by defining: the scintillation, σ; horizontal coherence, r_0; isoplanatism Θ_0; and the atmospheric frequency, f_0. The experiments also provide the data base from which AFGL is developing models of optical turbulence. The models of interest are boundary-layer models of the atmosphere's lowest three kilometers and upper atmosphere models for the 3 to 30 km altitude region.

An intensive measurement program to characterize optical propagation was conducted at White Sands Missile Range with the Atmospheric Science Laboratory. AFGL flew a total of 47 thermosondes at a desert site between September 5 and 25, 1984. Thermosondes are fine-wire tungsten resistors, horizontally separated by a space of 1 m, and mounted on an ascending weather balloon platform. The thermosondes measure turbulence fluctuations as C_n^2, the coefficient of the structure constant of fluctuations in the index of refraction, from the surface to 30 km. The altitude profiles of C_n^2 obtained by the thermosonde have an altitude resolution of 20 m. The profiles can be used to calculate the ground-based laser propagation parameters r_0, Θ_0, σ and f_0 mentioned above. An average daytime profile was calculated from 21 flights. Seventeen of these flights occurred between 1300 and 1500, and the other was launched at 0900. An average nighttime profile was similarly calculated from 18 night flights. Eleven of these flights occurred between 2000 and 2200; the others were launched at 0400.

AFGL operates a stellar scintillometer which can measure coarse C_n^2 profiles at night. Scintillometer measurements were conducted at the Sandia Optical Range on Kirtland AFB, New Mexico, and at Boulder, Colorado. The Boulder experiments successfully compared C_n^2 measurements by thermosonde, scintillometer, and VHF radar. The effect of the nearness of the mountains was apparent in the enhancement of turbulence levels.

Optical turbulence above the boundary layer of the atmosphere (typically above about 1 – 3 km) is believed to be caused by localized breaking of internal gravity waves. For this reason, AFGL conducted a study on the physical nature of these waves with the expectation that this would enhance our ability to model optical turbulence. Spectra of high-altitude, high-resolution wind-velocity fluctuations in the stratosphere were obtained from widely different times and geographic locations. When the individual spectra are superimposed, they clearly show a universal spectrum, as seen in the figure.



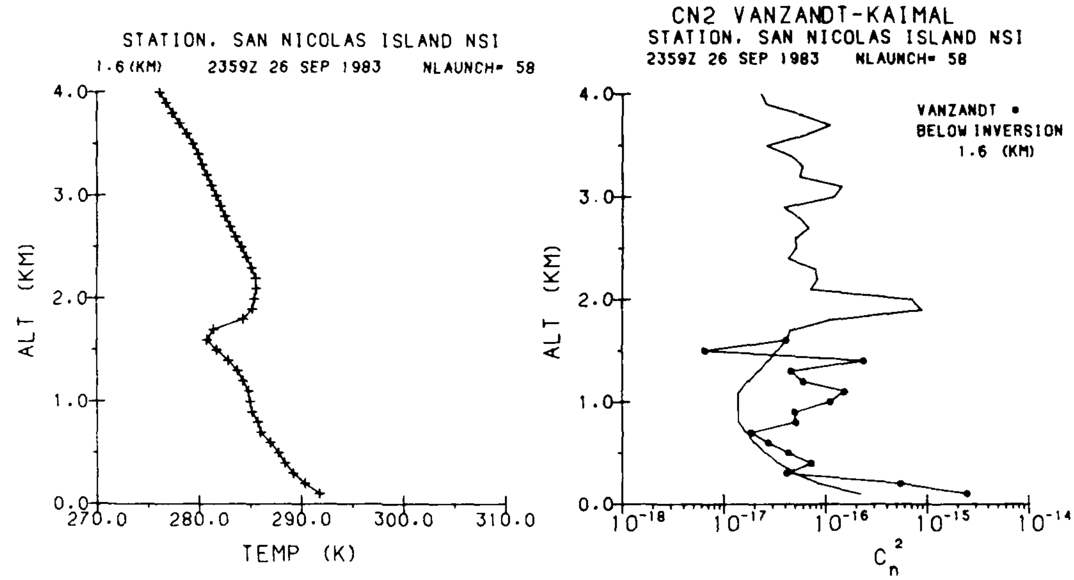
Photographic measurements of smoke release trails provide data for determining spectra of high-altitude wind velocity fluctuation measurements in the stratosphere. (These profiles from data taken at different times and latitudes provide important evidence of a universal spectrum.)

To explain this observation, which has historical precedent in observations of the ocean and troposphere, a model was proposed which accounts approximately for both the shape and the universal property. This model is based on the hypothesis that the waves grow with altitude and cause turbulence due to "convective instability." As soon as any wave component reaches its saturation amplitude, it loses energy to mechanical turbulence, thus generating optical turbulence.

A model for optical turbulence relating radiosonde observations to the optical turbulence parameter C_n^2 was created on the basis of the convective instability mentioned above and the detailed wind data used to create the power spectral density (PSD) spectra of the wind fluctuations. This model was compared to actual in-situ measurements as well as other models (see the figure). It has the advantage of simplicity without the loss of accuracy.

The refractivity turbulence structure constant, C_n^2, is the most important parameter in determining the effects of clear air turbulence on an optical beam. In the free atmosphere (at altitudes sufficiently high so that boundary-layer effects are negligible), the VanZandt model can be applied to rawinsonde data to calculate C_n^2 as a function of altitude. This leads to values of this parameter from about 2 km up to 25 km.

The coherence length, r_0, of an optical beam is related to the integral of C_n^2 through the atmosphere down to the observation point. In many cases the boundary-layer contribution (not covered by the Van-Zandt model) is quite significant, and values for C_n^2 are needed in this range. A model, partly empirical and part-



The high-resolution temperature plot on the left reveals a pronounced temperature inversion with a base at 1.6 km. The plot without symbols on the right depicts the VanZandt Model above 1.6 km and the Kaimal Model below 1.6 km. (The VanZandt is extended (curve with symbols) below the inversion layer only for comparison purposes and does *not apply in the boundary layer region.*)

ly theoretical, due to Kaimal has been used for this purpose. This model's range of validity is expected to be from the first temperature inversion layer down to about 0.1 km. The Kaimal model and the VanZandt model are used to calculate C_n^2 *from 0.1 km up to 4 km (see the figure).*

The model was applied to data obtained from high-resolution rawinsonde measurements conducted by personnel of the Pacific Missile Test Center. These measurements were obtained at three sites within 75 mi of one another in the proximity of Los Angeles, California: Point Mugu, El Segundo and San Nicolas Island. With two exceptions, C_n^2 was calculated using the Kaimal/VanZandt model only when a well-defined inversion layer was found at altitudes above 1 km. For a low-lying or nonexistent inversion layer, the effects of the Kaimal model are insignificant. The resulting C_n^2 profiles were then used to derive coherence-length estimates for the measurement period.

The temperature inversion layer is obtained from high-resolution balloon-launched thermistors. The VanZandt model can then be applied above the base of the inversion. A reference value of C_n^2 is derived from the VanZandt model and is used to generate the Kaimal model down through the boundary layer (below the inversion layer). It is then possible to integrate over the range of the two models to obtain r_0 (coherence length) and θ_0 (isoplanatic angle) necessary for the optical design of compensation systems to overcome atmospheric turbulence effects.

LIDAR TECHNOLOGY

During the twenty-year period since the first invention of the laser as a research tool, the commercially available laser sources have become sufficiently reliable that they may now be successfully applied to many areas of research. The development of laser-sounding technology for measurement of atmospheric properties is being carried out as part of the AFGL program in atmospheric optics. By measurements of the backscattered signal from a high intensity laser pulse as it interacts with the atmosphere, properties of the atmosphere along the beam path can be detected. The AFGL research program

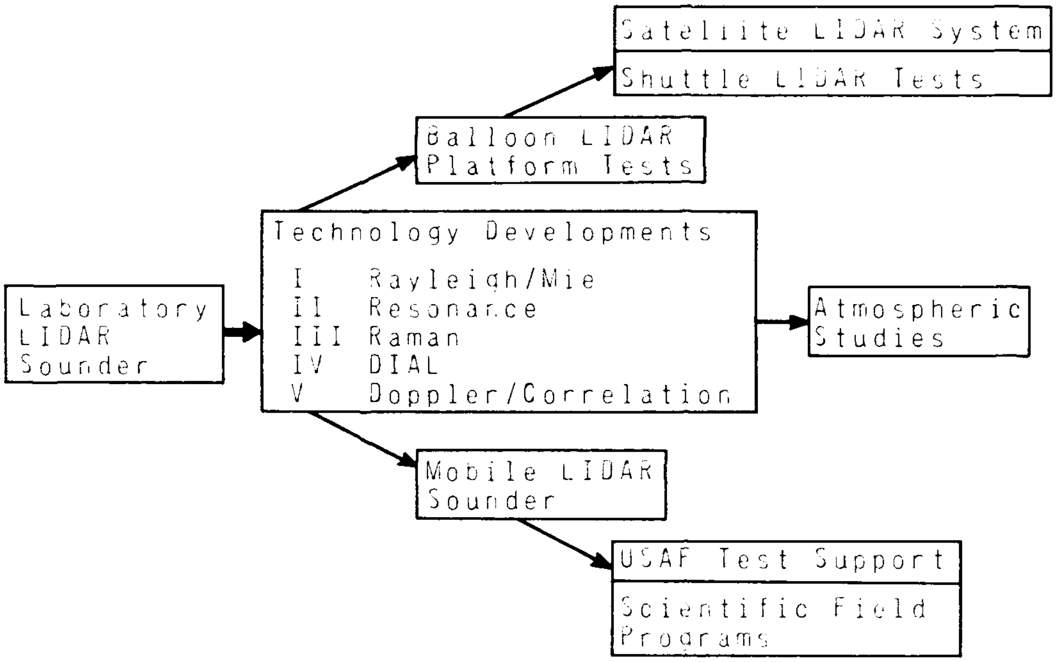
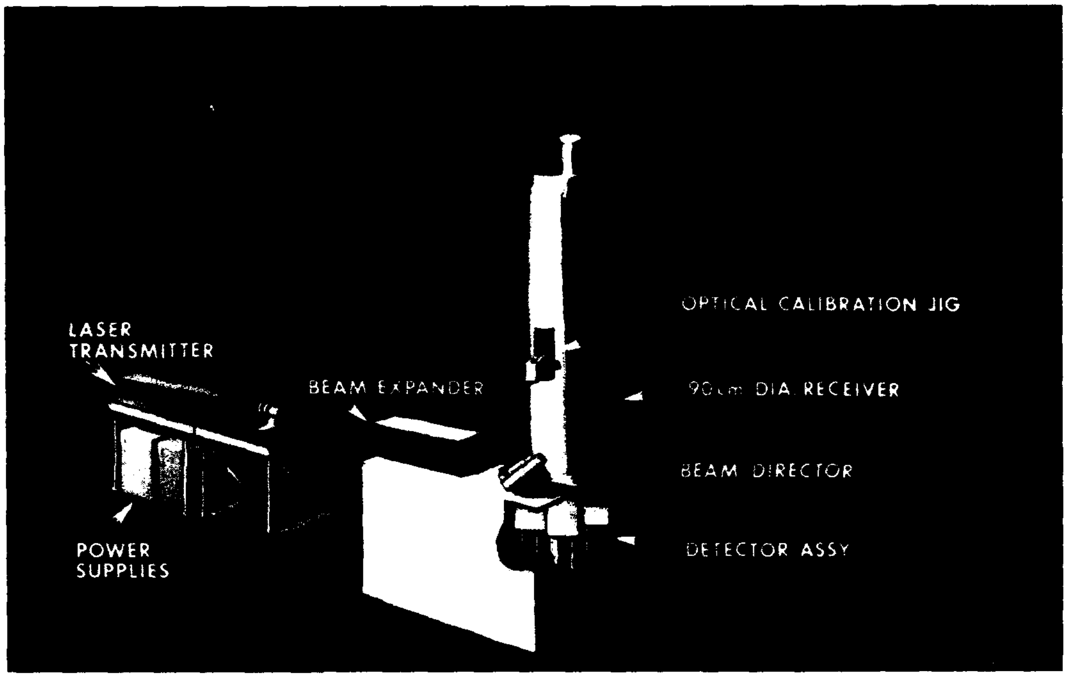


Diagram of AFGL LIDAR Program.

in the area of laser sounding technology includes several efforts. The program is centered on a laboratory program to develop and improve the measurement techniques. One laboratory facility is called GLEAM (Ground-based Lidar Experiment for Atmospheric Measurements). The program has two major areas of application as shown in the figure: a mobile lidar to support Air Force test programs and space-based applications for lidar as a tool for measuring global atmospheric properties. The development of the various technology areas for measurement of atmospheric properties also results in evaluation of the atmospheric effects on propagation of the laser radiation.

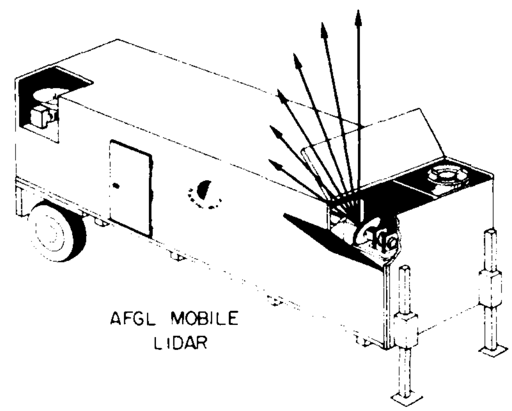
GLEAM Sounder: The GLEAM lidar sounder has been prepared in a laboratory on the roof of AFGL. It was first used to acquire atmospheric data in August, 1983. The initial measurements have been focused on using Rayleigh scattering to measure the molecular density profiles in the middle atmosphere. In the altitude region where molecular scattering predominates, the relative density profile can be obtained by range resolve measurements of the back-scattered photons from the laser beam. Generally, the region above 20 km is sufficiently low in particulate scatterers that the return of molecular scattering predominates. Following the eruptions of recent volcanoes, particularly El Chichon, there was an increase in the altitude range and intensity of particulate scatterers. The layers of Mie scattering observed at our latitude occurred from altitudes as high as 33 km during the winter of 1983. The Phase I development for measurements of atmospheric structure from the two-color lidar allows an independent determination of the regions where significant particulate scattering occurs. The Phase I measurements are made using the Nd:YAG laser at its doubled, 532 nm, and tripled, 355 nm, wavelengths (see the figure). In regions of pure Rayleigh scatter, the ratio between the signals at the two wavelengths is constant. However, a large difference in the ratio of the molecular to particulate scattering cross-sections exists at the two wavelengths where particulate scatterers become important. The facility has been



GLEAM (Ground-based Lidar Experiment for Atmospheric Measurements) System.

used to measure the density and temperature profiles in the altitude region between about 25 and 60 km. The high altitude channel, which will cover the range between 60 and 90 km, was not in use until the end of 1984. During 1985 this instrument will be used to gather data on atmospheric structure properties between 20 and 90 km. The development of additional capabilities for resonance fluorescence, Raman, DIAL, and other techniques will be carried out during the next two years. As the various techniques are tested, they will be used for development of potential space flight applications and to support Air Force field test programs.

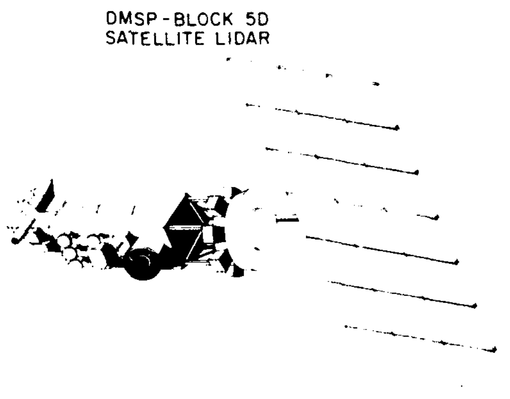
Mobile Lidar: There are three mobile lidar developments which are part of this effort. The transmission/extinction measurements are made over a few kilometer slant paths using a low-power Nd:YAG laser to obtain range-resolved data. This instrument is used together with path transmission/extinction measurements. This lidar has been employed for measuring the extinction in weather environments such as falling and blowing snow. A second mobile facility is intended to house a heterodyne detection CO^2 lidar for measurement of atmospheric winds and shears. The system uses a relatively high power electron-beam injection laser with the capability of 1 Joule pulse at 50 Hz. The instrument should provide measurements of the wind profile and aerosol scattering in the troposphere with a range of about 30 km. The instrument is currently being tested in the laboratory and will be transferred into its trailer in mid-1985. The third mobile lidar, referred to as GLINT (Ground-based Lidar Investigation-Transportable), is a large lidar facility, as shown in the figure, which will be used to field most of the developments from the GLEAM facility. Initially, this mobile facility will be used for demonstration of atmospheric measurement capability for the national ranges and for scientific or field-test measurements. The measurement capability will focus on Rayleigh and Mie scattering for atmospheric structure profiles. Capabilities for resonance fluorescence, Raman and DIAL measurements will be included later.



AFGL Mobile Lidar.

Space-Based Lidar: Lidar-sounding provides a unique capability for future measurements of atmospheric properties. Significant engineering and testing are needed but the technology is presently available to provide many improvements in global measurements of atmospheric properties. In August, 1984, AFGL was successful in obtaining data from a balloonborne lidar which flew at an altitude of 32 km above White Sands Missile Range (see the figure). The lidar included a Nd:YAG laser operated at the 532 and 355 nm wavelengths and used a 50 cm telescope receiver. Measurements were made with the instrument looking upward in the range of about 20 to 30 km above the platform and looking downward from the float altitude to the surface. During the flight, several different types of cloud layers and atmospheric conditions were present in the troposphere. The results from this flight are presently being analyzed. The platform will be used for additional developments of flight measurement capabilities. AFGL is also managing the engineering design for the first generation lidar sounder to fly on the DMSP satellite (see the figure). It will be used for measurement of cloud properties, aerosols, and surface albedo. Second- and third-generation space-based lidar developments will focus on measurement of thermodynamic properties, constituents, and wind structure.

Balloonborne Lidar Mounted on Gondola



Sketch of Lidar Sounder for DMSP Satellite.

MOLECULAR SPECTROSCOPY

HITRAN Database: The AFGL high-resolution molecular absorption data bases have been released periodically since the early 1970's. These compilations consist of the basic parameters required for the simulation of spectra, the resonant frequency, intensity, air-broadened half-width, and lower state energy of molecular transitions significant in a variety of radiative propagation problems in the atmosphere from the visible to the microwave region of the spectrum. The compilations consist of two atlases: (1) the Main atmospheric absorption line parameters compilation of the seven gases whose infrared activity combined with their natural abundances contribute to the principal opacity in certain regions of the infrared

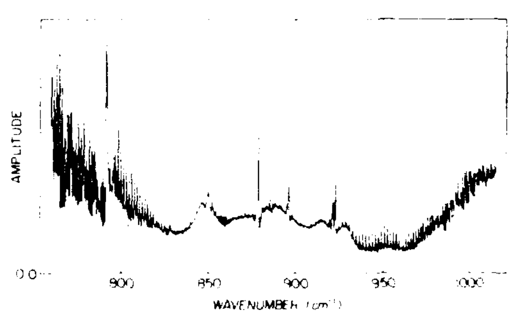
spectrum: water, carbon dioxide, ozone, nitrous oxide, carbon monoxide, methane, and oxygen; (2) the Trace Gas compilation, which incorporated during this period 21 additional gases, with molecular species contributing to attenuation in "window" regions of the atmosphere or to problems of retrieval and detection in the stratosphere.

Since the release of the last editions of both of these compilations, research has proceeded along several lines. The principal effort has focused on the improvement of the major infrared absorbers. New high-resolution measurements have been made of water vapor to extend and improve the HITRAN database in the short wavelength region of the visible because of the special interest in visible and ultraviolet lasers. Extensive high-resolution observations have been conducted at AFGL, the solar facility of Kitt Peak National Observatory, and the University of Paris at Orsay, France, to provide improved line positions and intensities of carbon dioxide throughout the infrared. This measurement program has been coupled with a theoretical program in the Optical Physics Division for calculating carbon dioxide intensities of bands involved in high temperature radiance. Theoretical programs have also yielded new parameters of collision-broadened halfwidths to improve capabilities of remote sensing and retrieval of atmospheric profiles. High resolution calculations of nitric acid in the 11-μm region have been added to the Trace Gas atlas and now provide good simulation of the strong features in this window region at stratospheric altitudes.

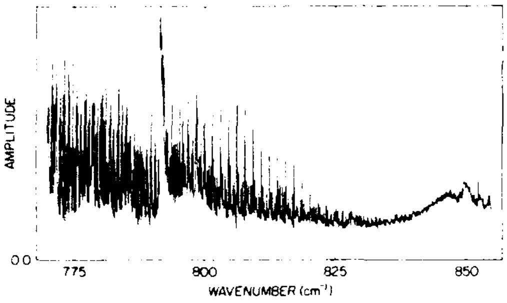
Laboratory Spectroscopy: In the high resolution laboratory of the Division, measurements at high temperatures (800°K) have been performed for several isotopic species of carbon dioxide enriched with ^{13}C and ^{18}O. Two regions of the spectrum were investigated, 4.5 μm and 2.8 μm. The former region had not been examined before in high resolution and is a region of interest for high temperature CO_2. The ensemble of vibration and rotational levels observed with the Fourier transform instrument at AFGL has provided new knowledge of the potential function of carbon dioxide from which advances in the variational theory for polyatomic molecules is being carried out.

Balloonborne Measurements: A cryogenically cooled interferometer spectrometer was flown as part of the AFGL SCRIBE (Stratospheric Cryogenic Interferometer Balloon Experiment) program to obtain emission spectra of atmospheric species. The cat's eye interferometer is cooled to liquid nitrogen temperature and has a GeCu detector which is cooled to about 10°K. The SCRIBE instrument operated successfully during two balloon flights: one in October, 1983, and one in July, 1984. The spectra presented in this report were obtained during the 23 October 1983 flight. The balloon was launched at 0610 MDT from Holloman AFB, New Mexico, and ascended at an average rate of 250 m/sec. During ascent, the instrument was operated so that it looked at an elevation angle of 7°. The interferometer was carried up to a float altitude of 30 km and data were obtained at several look angles, including nadir.

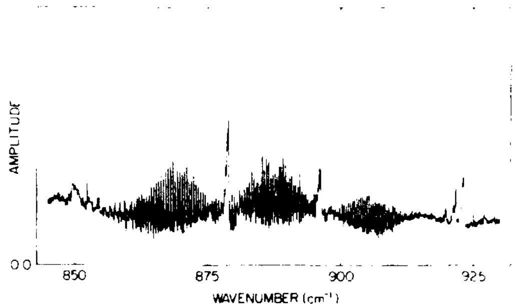
An emission spectrum covering the 750 to 1000 cm^{-1} "window" region of the atmosphere taken at a float altitude of 30 km is shown in the figure. The resolution was



Atmospheric Emission Spectrum Obtained from an Altitude of 30 km; Viewing Angle -3.2°. (This spectrum shows emission in the 800 cm^{-1} to 1000 cm^{-1} window at a resolution of 0.12 cm^{-1}. The emission in the 845-850 cm^{-1} region is due to $CFCl_3$; in the 850-910 cm^{-1} region to HNO_3; in the 910-935 cm^{-1} region to $CFCl_2$ and in the 950 cm^{-1} region to CO_2.)



a. 775 cm^{-1} – 850 cm^{-1}.



b. 850 cm^{-1} – 925 cm^{-1}.

Atmospheric Emission Spectrum Obtained from an Altitude of 30 km, Viewing Angle −3.2°.

degraded to 0.12 cm^{-1} in order to present a broad spectrum; the dominant emitting species are also indicated. The next figure illustrates the capability of the SCRIBE interferometer. The resolution is 0.06 cm^{-1} and the scan time of the interferometer is 25 sec. This spectral region (10 to 13 μ) is considered an atmospheric "window" and, even at 77°K, a sensor is easily capable of detecting the emission from trace gases in the stratosphere in this spectral region. In the upper troposphere and lower stratosphere in the 10 to 13 μ region, the emission is due to HNO_3, $CFCl_3(F_{11})$ and $CF_2Cl_2(F_{12})$. Generally, these compounds are not considered in meteorological radiative transfer calculations, yet at these altitudes they dominate the radiative transfer through this wavelength range. The July, 1984, flight yielded more and better data, which are presently being reduced for analysis.

INFRARED EARTHLIMB AND ZODIACAL BACKGROUNDS

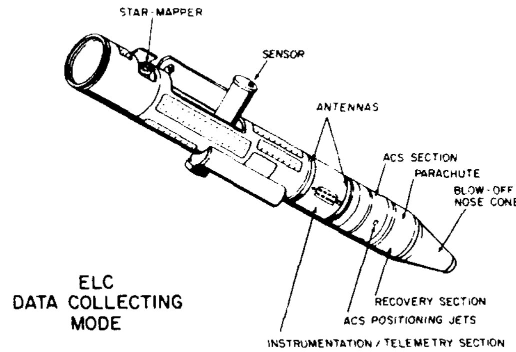
It is impossible for an infrared sensor to look in any direction without encountering the emission or radiation from some "background"—the celestial sky, the earth and clouds, the horizon or earth limb, or the atmosphere itself, the airglow. Much of the research of the Optical Physics Division is devoted to obtaining direct measurements of these backgrounds and developing data bases, models and codes to describe these backgrounds and the phenomenology related to them.

The Air Force needs to detect infrared-emitting targets in space at the greatest possible range. Because the targets are always viewed against the background radiance, knowledge of this radiation is necessary to permit discrimination of the target from the background. For space-based LWIR systems these backgrounds include radiation from the earth limb, zodiacal emission, and the celestial sky.

Earth Limb Measurements: An LWIR rocket probe experiment was successfully launched from an Aries booster by the Air Force Geophysics Laboratory from White Sands Missile Range, New Mexico, on October 25, 1983. The Earth Limb Clutter (ELC) experiment was the final rocket-probe measurement carried out under the joint AFGL/Space Division Background Measurements Probe Program.

The ELC experiment used a liquid-helium cooled LWIR sensor designed to optimize sensitivity and spatial resolution in order to carry out measurements of upper atmospheric earth-limb radiation (see the figure). Measurements were made in the limb-scanning geometry at predawn, looking primarily at the night sky. The experiment took place during very quiescent atmospheric conditions ($K_p = 1^{-}$, $F_{10.7} = 90$).

The overall length of the payload was 203 in. and approximate weight was 1315 lb. The payload was of aluminum construction. To provide a structurally stable reference between the sensor and star-mapper lines of sight, the sensor housing section was made from a single weldment. The infrared sensor was mounted on a one-



ELC DATA COLLECTING MODE

Earth Limb Clutter (ELC) Payload Configuration.

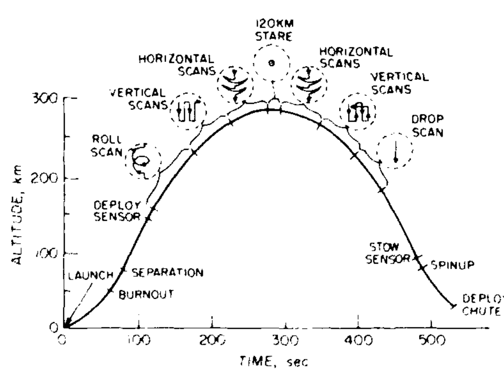
axis gimbal aligned orthogonally to the payload axis. The sensor deployment angle during the flight was fixed at 90° to the payload axis. Scanning motion was generated by cold gas reaction jets activated by a preprogrammed attitude control system.

The measurement sequence of the ELC mission is divided into five distinct scanning patterns, as shown in the figure:

1. Roll Scan - The payload is held in the vertical position, which puts the sensor zenith angle at 90°. A roll scan is generated which, in conjunction with the payload trajectory motion, generates an upwardly moving spiral scan pattern.

2. Vertical Scan - Eight separate scans are distributed about the apogee. The azimuthal angles range from -30° to +30°.

3. Horizontal Scan - There are four separate azimuthal scan sequences. The sensor sweeps scalloped patterns through the atmosphere as shown in the figure.



Earth Limb Clutter (ELC) Flight Profile.

4. Stare Mode - The payload is locked into a fixed orientation for 10 sec to study short-term temporal variations in the background.

5. Drop Scan - The trajectory motion is used to scan the atmosphere. It provides a fine spatial sampling of the atmosphere between 220 km and 100 km when the sensor is stowed.

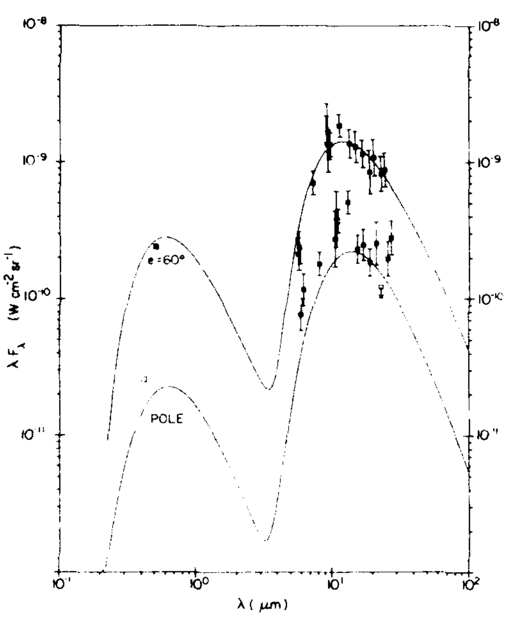
The various scan patterns combine to form grids of data in terms of altitude and azimuth. When the data are combined, they will provide a characterization of the spatial patterns in the LWIR background radiance.

Zodiacal Background Measurements: The zodiacal light, both scattered sunlight and thermal emission from dust particles in the solar system, is the limiting background for observations made from a space platform. AFGL successfully launched and recovered two rocketborne experiments designed to measure the 2–30 μm infrared emission from the dust. The cryogenically cooled telescopes, which were built, tested and calibrated at the Laboratory, are advanced off-axis, folded, doubly reimaging optical systems which represent the current state of the art.

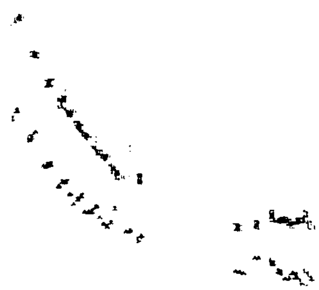
These experiments measured the zodiacal light at solar elongation angles between $22° \leq \epsilon \leq 180°$ and at elevation angles from the ecliptic plane between the North Ecliptic Pole and 60° South ecliptic latitude. The data have been processed and analyzed at the laboratory. The figures show the measured zodiacal light spectra and the measured intensity as a function of solar elongation angle in the ecliptic plane.

A simple preliminary model of the interplanetary dust cloud has been developed and fit to these experimental data. This model will be refined over the course of the next several years as more data become available from the NASA IRAS and COBE explorer missions.

The next generation of space experiments will use infrared sensors having high spatial resolution and high sensitivity. The Laboratory has begun a design



Measured Spectra of the Infrared Zodiacal Light at Solar Elongation of 60° in the Ecliptic Plane and at the North Ecliptic Pole. (Visual data are taken from *Astrophysical Quantities*.)



Infrared Intensity from Dust in the Ecliptic Plane at λ 10 μm (upper) and λ 20 μm (lower) as a Function of Elongation Angle from the Sun.

study effort to develop the sensor characteristics. This program is named LAIRTS, the Large Aperture Infrared Telescope System. The launch of this cryogenically cooled, meter class aperture telescope system is expected in the early 1990's.

Celestial Backgrounds: Two LWIR celestial survey telescopes of moderate size, and primary aperture of 36 cm were successfully flown during the reporting period. The Far Infrared Sky Survey Experiment (FIRSSE) made measurements in four spectral bands covering the wavelengths from 16 to 120 μm. FIRSSE was the first spaceborne experiment to successfully use super fluid helium as a cryogen under active thermal loading and the first to conduct a large area survey at 100 μm. The long wavelength observations from FIRSSE have been analyzed and published in catalog form (AFGL-TR-83-0055). The Survey Program of Infrared Celestial Experiments (SPICE) obtained survey data on the three spectral bands between 8 and 30 μm. These data plus the short wavelength measurements from FIRSSE provided an update to revise the AFGL Infrared Sky Survey Catalog (AFGL-TR-83-0161). Image processing of the celestial survey data produced diffuse maps of the Cygnus region and other regions of star formation. The preliminary AFGL celestial background model has been developed from analysis of these observations. This model offers a statistical description of the density of sources as a function of brightness and celestial position.

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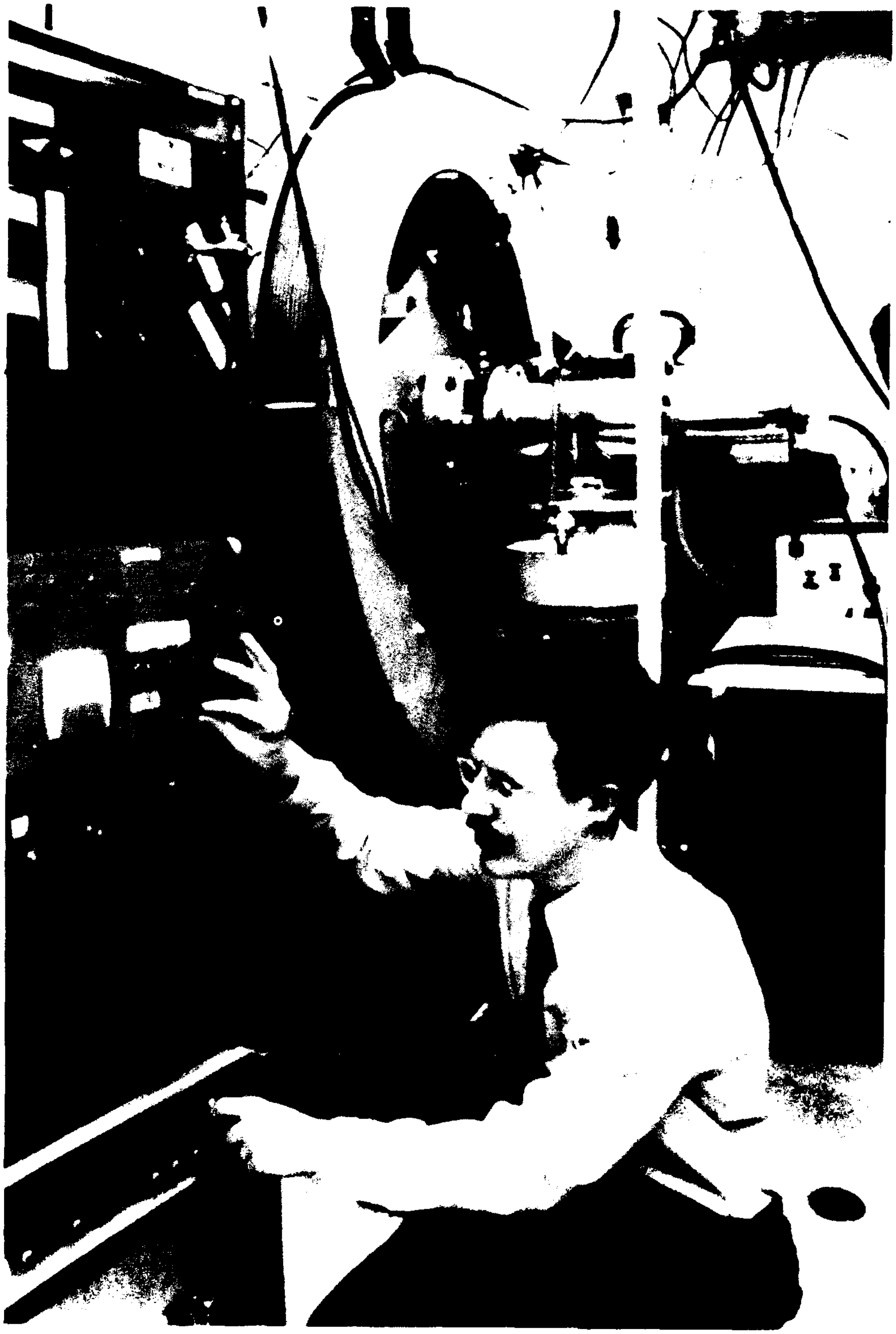


Adjusting the Laboratory Cold Electron Dependent Emission (LABCEDE) Apparatus to Measure the Infrared Emission from Gas Samples Irradiated by Electron Beams.

VIII INFRARED TECHNOLOGY DIVISION

The Infrared Technology Division performs research on the infrared emissions of the earth's atmosphere to determine the spectral and spatial nature of this radiation, to identify the physical and chemical processes producing the emission, and to understand its variability with geophysical conditions. This information is required to assess the ability of proposed and conceptual Air Force infrared surveillance systems to detect and track a target.

Ambient atmospheric infrared radiance varies markedly with altitude (with and without solar illumination), with latitude, and with solar and geomagnetic activity. Very significantly enhanced infrared emissions occur in polar regions during periods of auroral activity at altitudes in excess of approximately 90 km. They are produced by the distinct processes initiated by the collision of energetic particles with the atmosphere. In addition, nuclear detonations produce copious amounts of infrared radiation that is intense, persistent and highly structured.

Research on atmospheric infrared processes is pursued by the Infrared Technology Division in laboratory studies, in ground-based field measurement programs, and in airglow and auroral sounding-rocket probes. The results from the various experimental programs are interpreted and quantified in terms of specific physical or chemical processes, which are included in models of infrared atmospheric airglow and auroral emissions. The infrared airglow and auroral models provide designers of infrared systems an ability to

assess proposed designs for the detection and tracking of targets as projected against a variety of backgrounds.

LABORATORY STUDIES

Specific atmospheric processes producing infrared emission are studied in a series of different laboratory facilities using a variety of excitation mechanisms. The laboratory studies offer the unique opportunity to investigate specific microscopic chemi-dynamic processes under controlled conditions. Specific parameters, collision cross sections, rate coefficients, detailed vibrational populations, collisional deactivation rates, and radiative lifetimes are measured for the specific electronic and vibrational states of a given species. These parameters characterize the significance of a given process as a source of atmospheric infrared radiation in the ambient atmosphere or in aurorally or nuclear disturbed atmospheres. Results from the laboratory program are utilized to interpret airglow and auroral field measurements, which validate and confirm the significance of a given process. This approach has contributed significantly to the understanding of infrared atmospheric mechanisms. The laboratory experimental techniques include electron beam excitation, microwave discharge afterglow chemiluminescence, flowing afterglow studies with laser-induced fluorescence, Fourier transform mass spectrometry, and laser-induced plasma radiation.

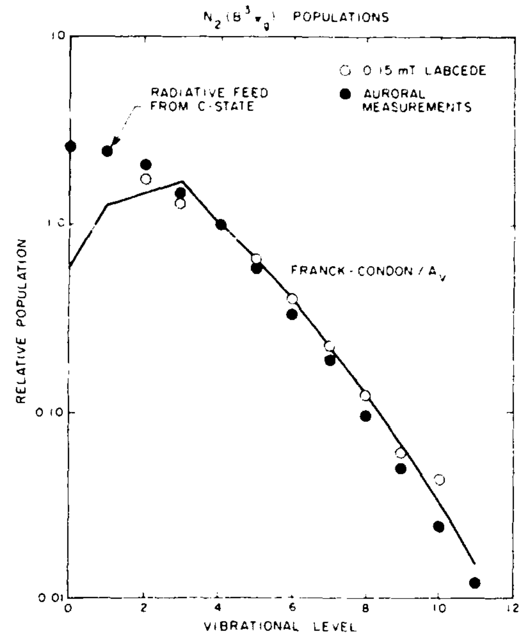
LABCEDE: In the LABCEDE (Laboratory Cold Electron Dependent Emission) program, the production of infrared radiation by the interaction of electrons with the constituents of the atmosphere is investigated. Two particularly important sources of bright, structured infrared background radiation in the upper atmosphere are the aurora and nuclear explosions. In both cases, collisions between electrons and the constituent molecules of the atmosphere result in the emission of infrared radiation. The atomic and the molecular species which radiate in the infrared are either excited directly by electron impact or are produced by chemical reactions which are initiated by electron scattering. The measurement of the relative efficiencies of excitation of those molecular states which are important sources of infrared radiation in the upper atmosphere, and the characterization of processes which control the brightness of those infrared emissions are primary objectives of the LABCEDE program.

Two facilities are used to investigate these electron-excited or -initiated processes. The cryogenic LABCEDE facility has been developed to make experimental measurements of infrared emissions from gas samples irradiated by electron beams. The internal walls of the system are operated at 80°K to reduce the thermal infrared background and to increase the detection sensitivity of the system by four orders of magnitude at 10 μ. As a result of the low thermal background and the large volume of the observation region, weak infrared emissions can be detected from samples at pressures corresponding to altitudes of 60 to 110 km. The gas samples can be irradiated by 6 keV electron beams of 20 mA, corresponding to an electron flux exceeding auroral excitation and comparable to the nuclear case. A magnetic field can be externally applied to control independently the density of incident electrons. The gas samples flow uniformly through the irradiation and the observation regions of the chamber.

An important capability of the cryogenic LABCEDE facility is the introduction of condensible species such as CO_2 and N_2O into the chamber when it is operated under cryogenic conditions. Another major feature of the facility is the exposure of the electron-beam irradiated sample to externally originating light beams, including a solar ultraviolet flux to simulate the daylight aurora, and laser beams to probe the characteristics of the sample. A medium-resolution spectrometer, a circular variable filter operated at 4°K, has been used to observe 2.4–15 μ infrared

emissions from electron-beam irradiated gas samples. Time-resolved Fourier spectroscopy has been utilized to provide high-sensitivity measurements of the time dependence of the 2–7 μ emissions from irradiated species. A fully cryogenic, very high resolution Fourier transform spectrometer will soon augment the capability of the Fourier transform spectrometer currently used. In addition, a spatially scanning photometer operated at 391.4 nm is used to monitor the deposition of energy by energetic electrons and to normalize excitation efficiencies to the production of ion pairs by the primary electron beam.

The excitation, and deexcitation by collisions, of various important radiators in auroras and the disturbed atmosphere have been measured using the cryogenic LABCEDE apparatus. The A state of N_2^+ is responsible for the very prominent nitrogen Meinel bands in the aurora. Relative rates for the excitation of vibrational levels 2–7 of the N_2^+ A state by electron impact have been measured. The rates obtained are consistent with those inferred from auroral measurements. The total cross section for production of the A state of N_2^+ by ionization of N_2 was also obtained. In addition, the rate coefficients for quenching vibrational levels 2–4 by air and quenching level 2 by N_2 and O_2 were determined. These measurements show that quenching of the Meinel bands becomes significant at altitudes below 100 km. The B- and W- states of N_2 are responsible for the First Positive and Wu-Benesch bands in the electron-disturbed atmosphere. The transfer by collisions of population from the W-state to the B-state of N_2 has been suggested to be responsible for the appearance of the lower red border type of aurora. The pressure dependence of First-Positive band emission from irradiated N_2 has been investigated using the cryogenic LABCEDE apparatus. For vibrational levels 3-10 of the B-state, the relative populations do not significantly depend on pressure over the equivalent altitude range of 60-110 km (see the figure). This result indicates that collisional

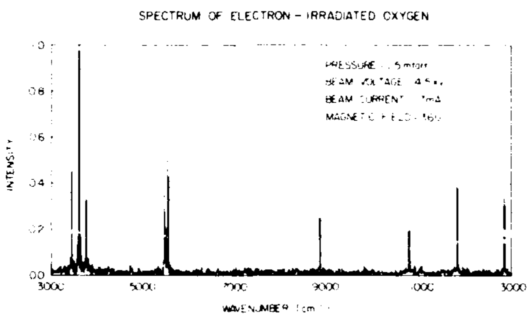


Relative Vibrational Populations of the Triplet B-state of N_2 as Observed by Irradiating 0.15 milli-Torr of N_2 in the Cryogenic LABCEDE Chamber and as Determined from Auroral Measurements. (The similarity in the vibrational populations indicates that the auroral processes account for the laboratory emission.)

coupling from the W-state to the B-state is not responsible for the lower red border aurora.

Atomic oxygen is an important infrared radiator in the highly disturbed upper atmosphere. The distribution over highly excited states of O produced by electron impact on O_2 has been investigated with the cryogenic LABCEDE facility at pressures sufficiently low that collisions do not disturb the atoms before they can radiate (see the figure). These measurements provide input to models of the infrared emissions of the atmosphere under highly disturbed conditions. Measurements currently underway with the cryogenic facility include determining the relative excitation efficiencies of the electronic states, vibrational levels, and infrared transitions of the important atmospheric radiators: N_2, NO, CO_2 and O_3.

A second apparatus is also used to characterize processes which produce infrared



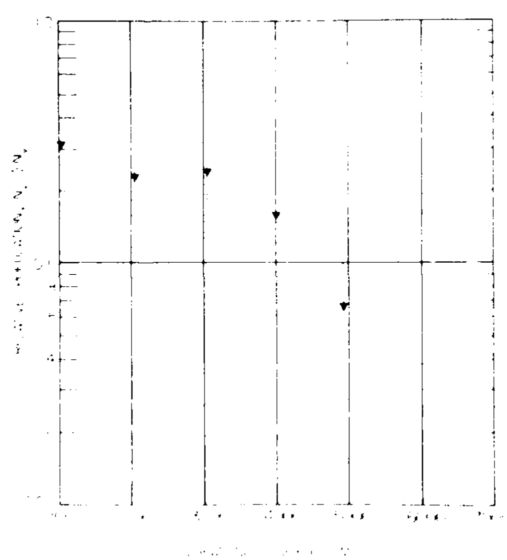
Spectrum of 0.7–3.3 μ Fluorescence of Atomic Oxygen in Electron-irradiated O_2 Observed under Collision-free Conditions Using a Michelson Interferometer. (Relative populations of radiating states can be directly related to production processes.)

fluorescence. In this LABCEDE facility, gas samples at pressures of 1-100 Torr are irradiated by 1-2 mA currents of 40 keV electrons. Recently, the production of NO in its lowest vibrational level by electron irradiation has been measured. The absorption of the output of a very narrow linewidth, tunable infrared diode laser monitors the production of NO. In addition, by irradiating mixtures of N_2 and trace quantities of NO, the production of N atoms by electron irradiation of N_2 has been measured. In this titration technique, the N atoms produced react with and deplete the initial concentration of NO, which is monitored by the infrared laser absorption technique.

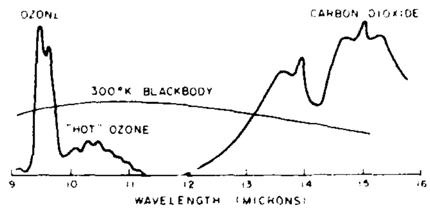
COCHISE: This helium-cooled cryogenic facility (Cold Chemiexcited Infrared Simulation Experiment) utilizes detection technology initially developed for space surveillance systems. The helium cooling allows cryopumping and background suppression, which results in extremely sensitive, "wall-less" conditions. A reaction vessel and spectrometer inside the cryogenic chamber are the main active components. Internal microwave discharge sources create radical species which are cross-mixed with reactants in a reaction region observed with a cryogenic spectrometer. This permits the observation of emission from excited species with number densities as low as 10^6 cm^{-3}.

Recently, data have been collected on the spectral extent of the emission from ozone formed in the three-body recombination $O + O_2 + M$. The relative population of the vibrational states radiating in the region near 10 μ has been determined, as shown in the figure. The significance of this measurement is also illustrated in the representation of atmospheric emission in the 9 to 16 μ region. Vibrationally hot ozone emissions originating from vibrational level 2 or higher in the ν_3 mode of O_3, extend to wavelengths greater than 10 μ, as shown in the figure. The region between 10 and 13 μ is a candidate region for detecting and tracking cold (300°K) targets in space. The window region is defined by the ozone and carbon dioxide atmospheric emission. Complete characterization of these emissions is required to optimize the operating wavelength of space-based surveillance systems. The COCHISE laboratory results indicate that the three-body formation of ozone produces no significant radiation beyond approximately 11 μ.

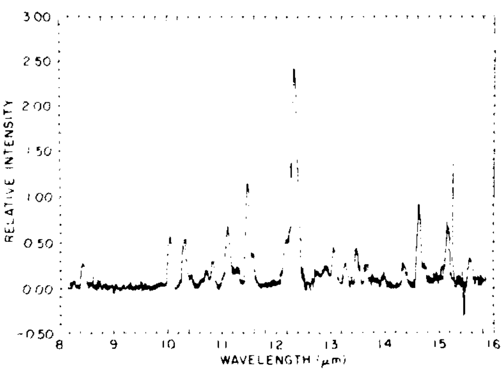
The long wavelength infrared emission of argon excited in a low-pressure microwave discharge has also been measured in the COCHISE facility. These results (see the figure) are the first reported observation of these emissions, indicative of the



Relative Amount of Ozone Distributed in Vibrational Energy Levels as Formed in the Reaction of $O + O_2 + M \rightarrow O_3 + M$.



Atmospheric Emission Character 9–16 μm, from Ozone and Carbon Dioxide, Superimposed on a Typical 300 K Blackbody Source. (Vertical axis is not to scale.)



Argon Infrared Emission Measured in the Cryogenic COCHISE Laboratory Facility.

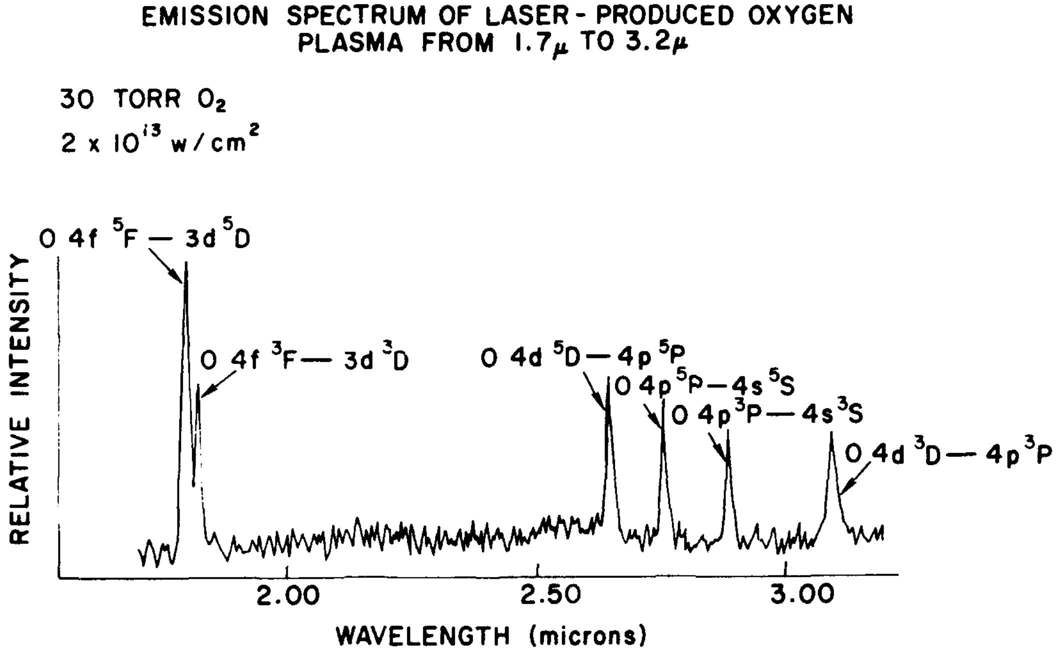
sensitivity of the cryogenic laboratory apparatus. Argon comprises approximately 1 percent of the atmosphere at altitudes below 100 km, and emissions from these transitions may be a significant source of LWIR radiation during nuclear detonations.

FACELIF: Laser spectroscopic techniques are applied to a standard flow-tube kinetics apparatus (Flowing Atmospheric Chemistry Experiment with Laser-Induced Fluorescence) to investigate detailed atmospheric chemistry pathways. One- and two-photon fluorescence and ionization achieved with a Nd: YAG pumped dye laser (with frequency doubler and Raman shifter) make this apparatus an extremely sensitive room-temperature technique for active probing of vibrational distributions of product molecules. This apparatus has been used to investigate the distribution of the vibrational state of NO formed in the reaction N $(^4S) + O_2 \rightarrow$ NO(v) + O. Considerable uncertainty exists in the scientific literature about the chemiluminescent band profile of nitric oxide formed in this reaction, and the present study will contribute to the resolution of that disparity.

A second experiment involving a color center laser has successfully measured CO_2 fluorescence from the (101) and (021) combination vibrational bands and is presently making further fluorescence measurements utilizing a Michelson interferometer to spectrally resolve two interfering bands. This will lead to the measurement of the branching ratios of the CO_2 combination band, radiating in the infrared at 2.7 μ and 4.3 μ.

LINUS: This laboratory technique (Laser Induced Nuclear Simulation) is designed to obtain information on the production rate of excited-state species and infrared radiation resulting from a plasma produced by a nuclear airburst. Conceptually, the experiment is very simple. The output from a 1.06 μm Nd: YAG laser is focused to a fine point inside a gas cell. The energy deposition results in the formation of a highly dissociated and ionized electrical gas breakdown region. The pressure in the cell can be controlled (corresponding to altitude), and the pure gas or gas mixture is specified. Power intensities approaching 1 gW cm $^{-2}$ can be achieved in the focal volume, which results in temperatures in excess of 100,000°K. Temporally resolved visible spectra are obtained with a standard monochromator and either an optical multi-channel analyzer (OMA) or photomultiplier tube/boxcar combination.

Two examples of infrared spectra recorded with a scanning grating monochromator show infrared atomic oxygen emissions from a recombining plasma (see the figures). The ions and electrons in the plasma recombine to form neutral oxygen atoms, which emit infrared and visible radiation. The results are the first measurements of infrared line emission in a recombining plasma, and the first reported observations of the oxygen atom spectrum in the 5 μ to 8 μ region. The O-atom infrared plasma emissions simu-



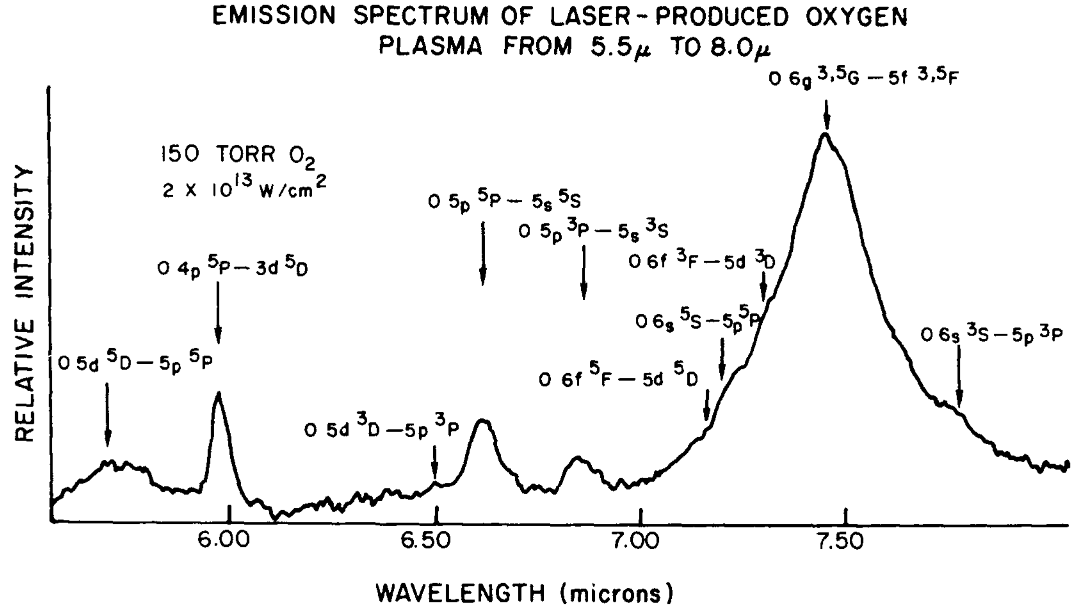
Atomic Oxygen Infrared Emission Induced in Molecular Oxygen by the LINUS Laser.

late nuclear-induced effects at high altitudes. Atomic-oxygen plasma radiation is anticipated to be a dominant high-altitude nuclear-induced infrared emission, and the LINUS facility provides an opportunity to identify line positions and intensities and to estimate LWIR nuclear-induced atmospheric effects.

FTMS: A Fourier transform mass spectrometer has been employed to study a variety of problems related to ion chemistry in the e: ~th's atmosphere. New analytical methods have been adapted to derive the spectrum from a time domain signal. The instrument itself has several attractive features such as simultaneous detection of all ionic species present, the capability to provide the time history of the parent or product ions, and multiple ion ejection for study of the behavior of a particular ionic species.

The heart of the apparatus is a cubical cell with six insulated sides imbedded in a homogeneous magnetic field produced by a superconducting magnet. Ions are created by . lectron bombardment of the neutral species in the cell at low pressures ($\simeq 10^{-8}$ Torr). The desired ionic species are then excited to cyclotron orbits by a fast rf chirp pulse applied to two opposite electrodes. Rather than measuring the power absorbed by th(accelerating ions as in a conventional ion-cyclotron resonance instrument, a FTMS measures the image current induced in the other pair of electrodes by the oscillating ions. The measured image current is a composite of harmonic currents with frequencies that are related to the mass-to-charge ratios of the ions. This current measured in FTMS creates a signal that constitutes the time-domain signal, later transformed into frequency (or mass) spectra through appropriate Fourier transformation.

Initial experiments with the FTMS included measurement of some very well known rate constants to assure system behavior and suitability for ion/molecule reaction studies. These included reactions of CH_3^+ and CH_4^+ with neutral methane to form $C_2H_5^+$ and CH_5^+, respectively. The rates obtained agreed with those established in the literature. Reaction of N^+ with molecular oxygen to form O_2^+, NO^+ and O^+ is of particular interest to this

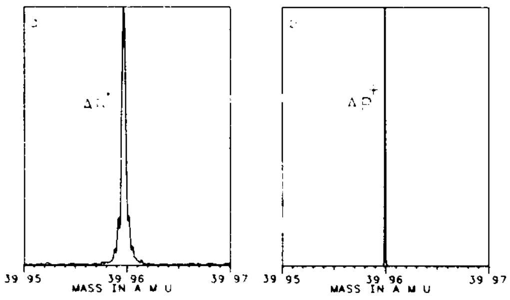


Atomic Oxygen Longer Wavelength Infrared Emission as Observed in the LINUS Experiment.

laboratory because NO^+ is formed with a large amount of energy available for population of $NO^+(v)$ vibrational levels and the potential subsequent infrared emission from these levels. Measurement of the rates in the FTMS system has yielded a total rate coefficient for the $N^+ + O_2$ reaction of 7×10^{-10} cm^3/sec, which is in agreement with existing values to within 15 percent. Results for the branching ratios into O_2^+, NO^+ and O^+ channels should resolve the uncertainties that are currently reported in the literature.

The FTMS experiment utilized a new spectral analysis method to obtain mass spectra from time-domain signals using only a few hundred points from the signal time series. The method, which is called the Maximum Entropy Method (MEM), was originally developed by geophysicists for application to geomagnetic phenomena where the fast Fourier transformation did not produce good spectral results because of a lack of long time-domain signals. In FTMS, good quality spectra are readily obtained when time-domain signals are long (consisting of 8 to 64 thousand data points). However, in the study of rapid chemical processes, it is desirable to use very few data points without sacrificing resolution in order to track the evolution of reaction products. MEM does exactly that. Briefly, MEM uses a few hundred points of the data to calculate the elements of a time-domain filter called the "prediction error" filter. Once the filter is characterized, its power response is calculated to obtain the spectrum. The sidelobes that arise in the fast Fourier transformation are avoided in the MEM and the resolution is enhanced by factors of ten or more, especially for data obtained in the heterodyne mode. A sample of the results derived by applying the new analytical method to the time signal obtained by FTMS using a single ion, Ar^+, is presented in the figure.

MAPSTAR: The goal of the MAPSTAR (Middle Atmospheric Periodic Structure-Associated Radiance) program is to investigate periodic structure in the natural D and E regions of the upper atmosphere. The nondisturbed upper atmosphere (in which neither auroral nor nuclear disturbances have occurred) is usually considered to be uniform in character, yielding predictable radiance levels. However, measurements of periodic structure have indicated that such a quiescent picture of the atmosphere is inaccurate. There



Mass Spectrum of the Singly Ionized Argon Obtained in the High Resolution Mode of FTMS.
a. Fast Fourier transform spectrum using 4096 data points.
b. Maximum entropy spectrum using the first 125 data points of the same data as in a.

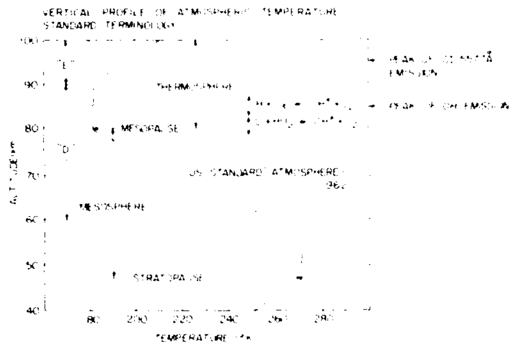
appears to be a broad range of temporal and spatial frequencies resulting from numerous potential sources. Such structure may be a serious source of system clutter, presenting operational constraints on infrared surveillance systems.

Several possible sources of structure in the upper atmosphere have been presented and discussed in the literature. Diurnal and semi-diurnal variabilities associated with solar and lunar tidal effects present potentially important sources of enhanced (or diminished) infrared radiance relative to a "standard" atmosphere. The time scales for tidal variability do not pose a clutter problem and may be generally treated as dispersions in the input model atmosphere for code calculations. More interesting sources of structure in the D and E regions are so-called "gravity waves," which are atmospheric waves whose frequencies are below the Brunt-Vaisala frequency (the natural oscillatory frequency of the atmosphere), which is 4-5 min in the D and E regions. These waves are caused by a number of possible geodynamical effects including storm fronts, earthquakes, wind interactions with orographic features, magnetospheric or solar activity and, certainly, nuclear events. Models predict that the motion of the major constituents (N_2, O_2) follows the gravity wave, and that the behavior of the minor constituents is determined by the major constituents' mass motion through dynamical pressure/temperature effects as the wave propagates through the atmospheric regions. The result is a periodic structure in the characteristic signatures of the minor species that are the source of infrared radiance (OH, H_2O, O_3, CO_2). Structure can also occur as waves either become unstable and break, or as their energy is dissipated, either of which results in turbulence. Such turbulent structure is generally shorter-lived than gravity wave structure but may occur at any time in a random spatial and temporal manner.

Observations of periodic structure in the D and E regions have been reported since 1950. Patterns in fluctuations in the atmospheric nightglow of OI (5577A) and OH Meinel (7300A-7400A) bands have emerged in more recent studies (see the figures). While the fundamental transition in OH occurs at 2.7 μ, this wavelength is absorbed in the lower atmosphere and thus cannot be detected from ground-based measurements. Overtone OH emission, however, is very easily measured from the ground in the Meinel bands. This gives an excellent in-situ indicator of the geodynamical effects occurring in the D region.

A coordinated effort to collect and assimilate data to establish a comprehensive understanding of the sources, prop-

Ground-based Intensified Television Image of Periodic Airglow Emission Originating from Approximately 85 km.



Atmospheric Altitudinal Definitions, Temperature Profile and Hydroxyl, OH, Airglow Processes.

agation, and signatures of structure resulting from waves in the upper atmosphere is being made at the Air Force Geophysics Laboratory. The structure of the D and E regions is observed using mobile, ground-based visible, infrared, and radar techniques. Preliminary measurements concentrating on the OH and OI emission regions, measurements of OH rotational temperature, band emission levels, OI emission levels, and radar returns from electron density gradients were obtained for several different conditions of D and E region behavior. An example of radiometer data of the OH v′, v″ = 3,1 intensity as a function of universal time is shown in the figure. For day 182 (June 29-30, 1984) the radiance level constantly oscillated through periods of slow build-up and sudden collapse. The fine structure evident is real and represents

Ground-based Radiometric Measurements of OH Airglow Variability for the (3-1) Transition Which Emits at 664 nm.

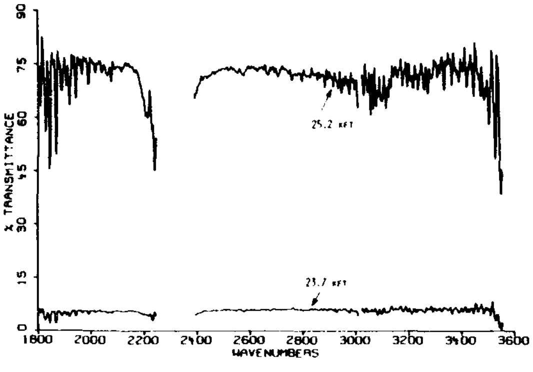
oscillation periods on the order of 4 min. The OII photometer results indicate a high-frequency component consistent with an acoustic branch. Simultaneously with the radiometer results, radar returns at 2.66 MHz showed a periodic collapse of the D-region return coincident with the sudden periodic decrease in OH radiance. If this represents a coupling of electron density to OH emission behavior, the result is neither expected nor understood at present and represents a new and potentially important area for D- and E-region structure investigations.

The preliminary results of the MAPSTAR experiments indicate a high occurrence rate of periodic structure in the natural upper atmosphere and suggest that the D and E regions are very dynamic and that periodic variability in spatial and temporal infrared radiance is quite common. It is likely that all important wavelengths in the infrared show periodic fluctuations in their radiance levels. The MAPSTAR project is intended to generate the basis for predictive codes for a comprehensive treatment of infrared structure which may generate severe clutter for a new generation of sensor systems.

AIRBORNE MEASUREMENTS

The Flying Infrared Signatures Technology aircraft is equipped as a comprehensive laboratory for in-flight research and measurement on the infrared phenomenology of targets and backgrounds. Radiometers, interferometers, spectrometers, and a variety of spatial mappers that produce TV-like images from infrared radiation are used to collect the basic data.

The long aircraft range of over 5000 miles permits worldwide deployment, and its ability to fly above 40,000 ft altitudes allows infrared scientists to study the environment from near sea level to well above the obscuring clouds and above nearly all of the atmospheric water vapor (see the figure). This aircraft is a reliable platform for the study of geographic, seasonal and diurnal variations of the sky, clouds and the earth. The flights are fre-



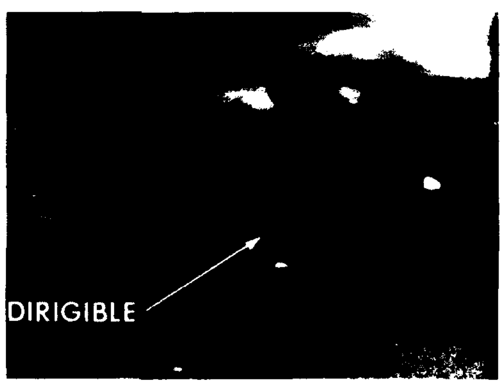
Aircraft-based Measurement of Infrared Cloud Transmittance Measured by Observing the Sun at Altitudes above (25.2 kft) and below (23.7 kft) the Cloud Layer.

quently coordinated with rocket launches and other test aircraft, which work in concert to study a common problem from differing aspects. In recent years a large part of the measurement capability has been employed to understand the in-flight infrared characteristics of aircraft. Unique measurements of the infrared radiation of the boost phase of missile launches have been obtained from this aircraft. The important role that the surrounding environment of land, sea, clouds and atmosphere play in influencing target infrared behavior, or "signatures," is being determined in detail. The data obtained are used to develop new models that can simulate infrared behavior and also to validate and test specific theoretical and laboratory based models.

As infrared technology has made large advances in recent years, the need for understanding the behavior and appearance of targets at high spatial resolutions and from long measurement ranges has become important. New complex infrared mosaic and scanning sensors introduce a whole new class of problems to be solved so that these instruments can be used successfully in weapon seekers, surveillance systems and for intelligence gathering by remote sensing. The flying infrared signatures technology aircraft provides an important platform from which to test new sensor concepts and to obtain detailed infrared characterization of the world so that new systems can achieve their development goals.

The aircraft has a variety of unique instrumentation. Five Michelson interferometers provide high-resolution spectral data. These instruments can look out the side of the aircraft over a wide range of angles when mounted in a special "eyeball" window mount. A gold-coated periscope mirror can also be inserted through the eyeball into the ambient airstream, allowing viewing in any direction simply by rotation of the periscope. This combination of mounts permits a target to be viewed anywhere in the hemisphere on the right side of the aircraft.

Three different kinds of thermal imaging scanners are available to be operated simultaneously with the spectral measuring interferometers. The imaging systems produce TV-like images from infrared radiation in the 2 to 14 μ spectral region. Two systems use an array of HgCdTe or InSb detectors to provide spatial data in a scene and to resolve temperature differentials less than 0.1°C. When mounted behind 7-in. aperture optics, these side-looking systems have a spatial resolution of better than 0.3 mrad. A third system using a Schottky barrier PtSi mosaic array with more than 7000 detector elements has been developed for the aircraft (see the figure), and an instrument with an array of more than 30,000 elements



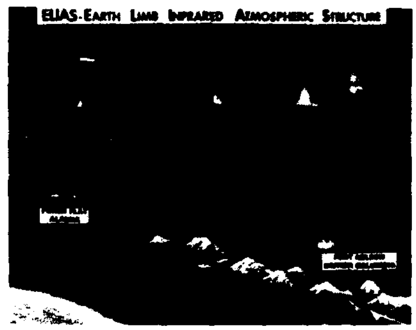
Aircraft-based Infrared Thermal Scanner Image of a Blimp Using a Schottky Barrier Array Detector. (The lighter regions represent the areas of high infrared radiance.)

will be operating soon which will be sensitive in the 1.0 to 5.0 μ region. These systems provide absolutely calibrated radiometric imagery in the infrared.

The airborne infrared measurements program collects large amounts of data from a variety of backgrounds and targets. Spectral and spatial data have been collected from desert, urban, cultivated, forested, mountain, snow, cloud and water backgrounds. Special flights have been used to measure the scattering and transmission of clouds when viewed from above, below, and through a variety of clouds. Flights have been made over selected terrain throughout the day to determine the diurnal variation of its infrared characteristics. A wide variety of targets have been measured. A forest fire from which the sensitive interferometers were able to detect large amounts of carbon monoxide was measured at a range of many miles. More than 30 types of aircraft have been measured over power settings from idle to maximum thrust and from 500 ft to 40,000 ft flight altitudes. Industrial sites, tanks, and ships have also been measured from a variety of flight altitudes.

AURORAL SOUNDING ROCKET PROBES

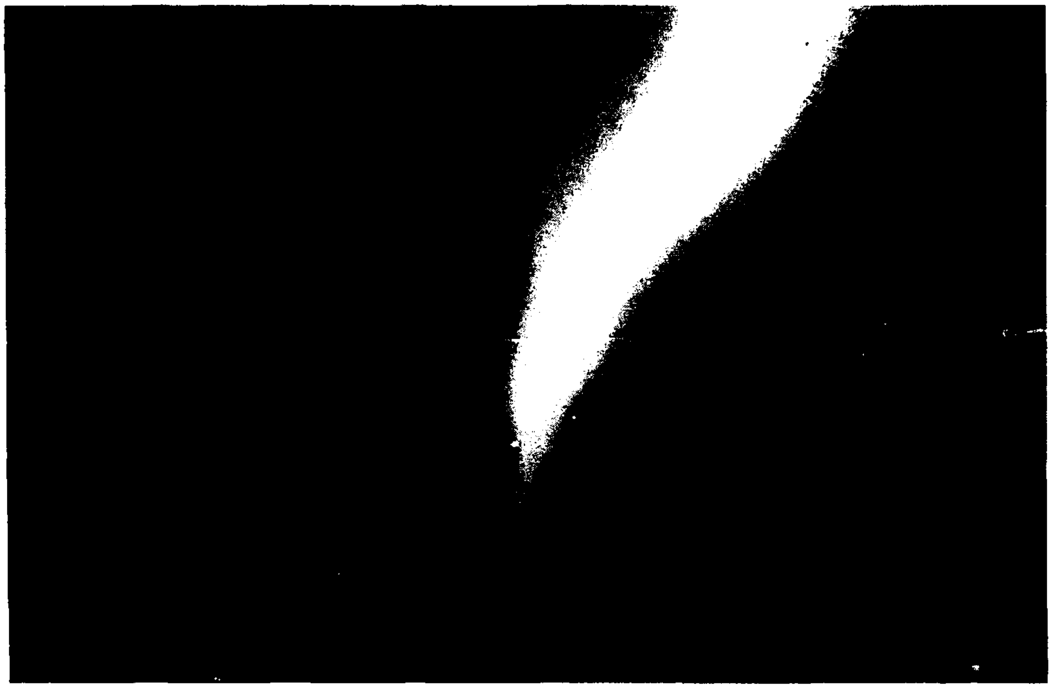
A rocketborne infrared experiment, sponsored by the Defense Nuclear Agency (DNA), called ELIAS (Earth Limb Infrared Atmospheric Structure) was flown from Poker Flat Research Range, Alaska, on March 19, 1983 (GMT), to measure the infrared spatial and temporal structures in bright, discrete auroral forms, as well as in the earth limb airglow (see the figure). The mission was successful and emissions from a class IBC III auroral breakup originating over Fort Nelson, Canada, were measured using staring, vertical, and horizontal instrument scanning modes (see the figure). The airglow region of the earth's atmosphere was also observed. Measurements were obtained in four different wavelength passbands while the payload was exoatmospheric. The primary instrumentation was a three-color, telescoped, cryogenic radiometer containing three coaligned linear arrays (five detectors each) in the detector focal plane with individual pixel dimensions of 1 mrad x 1 mrad. The supporting instrumentation onboard the payload included an image intensified television camera, a celestial aspect star sensor, and a horizon sensor. Ground instrumentation at Fort Nelson, British Columbia, simultaneously documented the same auroral event observed by ELIAS.



The ELIAS Experiment Concept and Earth Limb Viewing Aspect.

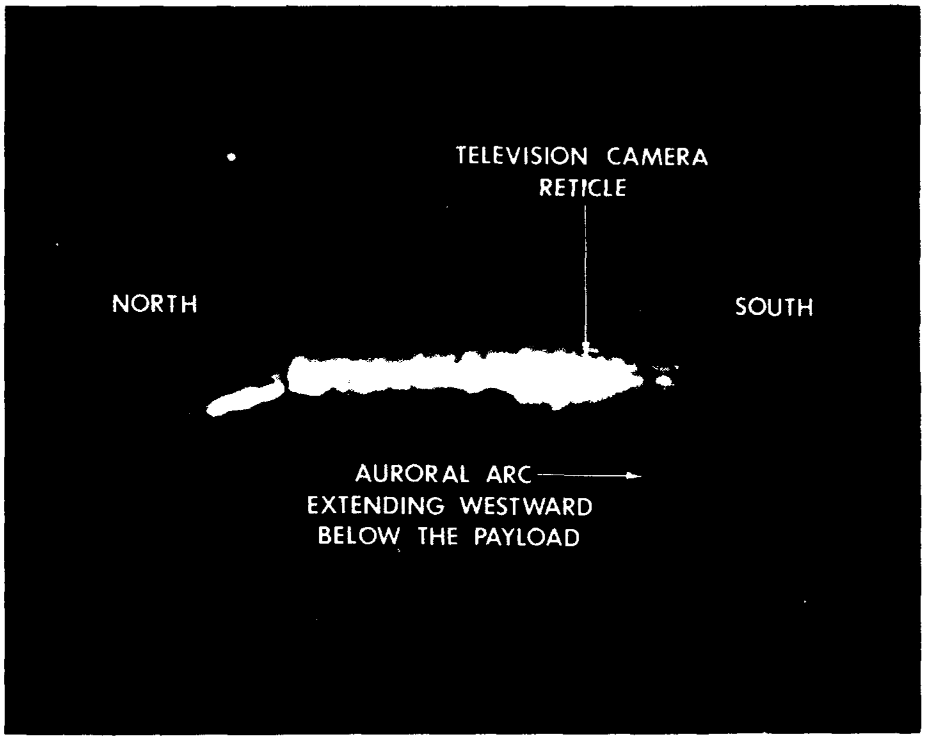
The measurements show highly structured and intense infrared emissions which are correlated to ultraviolet emissions at 3914Å and near-infrared emissions at 9000Å (see the figure). The data are significant because they constitute the first documented exoatmospheric limb-viewing evidence of molecular infrared spatial structure in the aurorally disturbed, high-latitude atmosphere. In addition, the data are directly applicable to evaluating performance capabilities of existing and potential military surveillance systems.

In April, 1983, a Field-Widened Interferometer (FWI-II) was successfully flown into an auroral event on a Sergeant rocket from Poker Flat, Alaska, and was recovered in excellent condition after descent by parachute in the final phase of the trajectory. Infrared spectra from 2.0 to 7.5 μm



Ground-based View from Ft. Nelson of the Auroral Breakup During the ELIAS Experiment. (The range from the rocket payload to the tangent altitude above Ft. Nelson is approximately 1500 km.)

(5000-1333 cm^{-1}), with 1.1 cm^{-1} resolution, were obtained at approximately every kilometer or less of altitude from 85 to 139 km, on both the ascent and descent portions of the trajectory. A dual cryogen system was used, with liquid neon cooling the indium-doped silicon detector and liquid nitrogen cooling the optics and baffle. High sensitivity (NESR = 2×10^{-13} W cm^{-2} sr^{-1} cm at 5.0 μ) is inherent in the wide field of view (12 degrees) available with the FWI design. The instrument is ideally suited to measurement of extended sources such as aurora. The payload was oriented to look in the zenith direction throughout the measurements portion of the trajectory. On-board photometer measurements indicated that the sensor penetrated an aurora of low to moderate intensity which had experienced more intense auroral excitation prior to launch. A rocket-based energy-deposition scintillator measured the electron energy distribution. The most prominent auroral infrared emissions are indicated in the sample spectrum and were those from nitric oxide (NO) between 1675 cm^{-1} and 1950 cm^{-1} (5.4 μm band) and carbon dioxide (CO_2) between 2320 cm^{-1} and 2400 cm^{-1} (4.3 μm band). The first measurements of CO (see the figure) as an infrared radiation source in the upper mesosphere were obtained during the flight in the 2100 to 2200 cm^{-1} wavelength region. Hydroxyl (OH) data were also obtained during both the rocket ascent and descent and provide the first high-resolution measurements of OH as a function of altitude. The CO and OH emissions are being analyzed in terms of atmospheric concentration and production and loss processes.

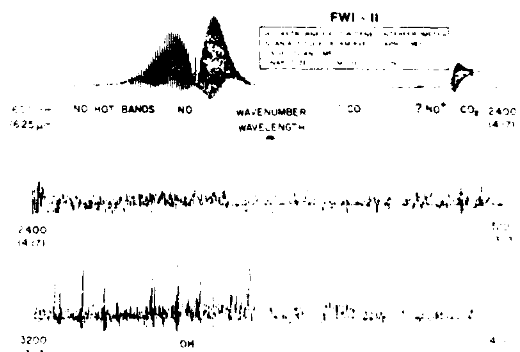


Earth Limb View of Aurora Shown in Preceding Figure as Recorded by the Image-intensified Television Camera Onboard the ELIAS Payload.

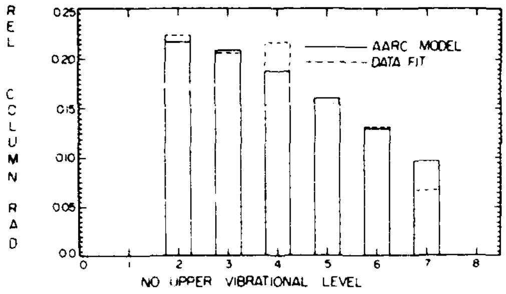
INFRARED ATMOSPHERIC MODELLING

Theoretical models of infrared emission from the quiescent ARC (Atmospheric Radiance Code) as well as the aurorally disturbed AARC (Auroral Atmospheric Radiance Code) are being developed. These models are being validated by analysis of data from the field experiments.

A recent example of the analysis of the field data is provided by the Field-Widened Interferometer (FWI) experiment. Clearly identified in the flight measurements are the radiation from the 4.3 μm band of CO_2 and the 5.3 μm fundamental band of NO. Also seen is the weak CO fundamental band at 4.7 μm. The spectrum of NO has been analyzed. It has been shown that this spectrum is composed of two parts: (1) the nitric oxide (1—>0) transition due to an airglow process originating from a broad altitude range with a maximum emission near 130 km and having a rotational temperature of about 550°K; and (2) auroral emission from the auroral hot bands (upper state vibrational levels two or greater), originating from around 130 km and having a rotational temperature of about 280°K. The absolute emission rates and band profiles from the auroral transitions are in



Rocketborne Measurement of Infrared Atmospheric Emission During a Low Intensity Aurora. (The CO_2 emission at 4.3 μm and the NO emission near 6.0 μm are enhanced by the electron energy deposited in the atmosphere during the low-intensity auroral activity.)



Vibrational Distribution of the Higher Vibrational Levels of Nitric Oxide as Measured by 5.4 – 6.0 μm Infrared Emission in a Low-intensity Aurora and as Modeled Based on Laboratory Measurements.

good agreement with the AARC modeled radiance based on the kinetic data from the AFGL COCHISE and LABCEDE experiments, as illustrated in the figure. The codes ARC and AARC are non-equilibrium codes and contain detailed production and loss processes for a given state of a species. They may be readily modified as specific processes are identified, or revised and include the effects of radiation transport. The models will be extended and improved as results from the laboratory and the field measurement programs become available.

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Absolute Production Rates and Efficiencies of NO in Electron Irradiated N_2/O_2 Mixtures
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AFGL-TR-84-0086 (March 1984), ADA144197

APPENDIX A

AFGL PROJECTS BY PROGRAM ELEMENT
FY 1983

Program	Project Number and Title	
61101F	ILIR	In-House Laboratory Independent Research
61102F	*DEFENSE RESEARCH SCIENCES*	
	2303G1	Upper Atmosphere Chemistry
	2303G2	Plume/Atmosphere Interactions
	2309G1	Geodesy and Gravity
	2309G2	Crustal Motion Studies
	2310G1	Molecular and Aerosol Properties of the Atmosphere
	2310G3	Upper Atmosphere Composition
	2310G4	Infrared Atmospheric Processes
	2310G6	Remote Ionospheric Mapping
	2310G7	Atmospheric Dynamic Models
	2310G8	Advanced Weather Satellite Techniques
	2310G9	Global Ionospheric Dynamics
	2311G1	Energetic Particles in Space
	2311G2	Magnetospheric Plasmas and Fields
	2311G3	Solar Environmental Disturbances
62101F	*GEOPHYSICS*	
	4643	Ionospheric Specification
	6670	Meteorological Development
	6687	Middle Atmospheric Effects
	6690	Upper Atmosphere Technology
	7600	Terrestrial Sciences
	7601	Magnetospheric Effects on Space Systems
	7659	Aerospace Probe Technology
	7661	Spacecraft Environment Technology
	7670	Optical/IR Properties of the Environment
63410F	*SPACE SYSTEMS ENVIRONMENTAL TECHNOLOGY*	
	2821	Space Systems Design/Test Standards
	2822	Interactions Measurement Payload
	2823	Charge Control System
63707F	*WEATHER SYSTEMS*	
	2688	Weather Systems (Advanced Development)
	2781	Next Generation Weather Radar

In addition to the continuing Air Force funded projects cited above, AFGL participates in joint programs supported by the following agencies:

1) U.S. Air Force
   - Space Division
   - Ballistic Missiles Office
   - Air Force Weapons Laboratory
   - Air Weather Service
   - Electronic Systems Division
2) Defense Advanced Research Projects Agency
3) Defense Mapping Agency
4) Defense Nuclear Agency
5) Defense Communications Agency
6) Department of Energy
7) National Aeronautics and Space Administration
8) Navy

AFGL PROJECTS BY PROGRAM ELEMENT
FY 1984

Program	Project Number and Title	
61101F	ILIR	In-House Laboratory Independent Research
61102F	*DEFENSE RESEARCH SCIENCES*	
	2303G1	Upper Atmosphere Chemistry
	2309G1	Geodesy and Gravity
	2309G2	Earth Motion Studies
	2310G1	Molecular and Aerosol Properties of the Atmosphere
	2310G3	Upper Atmosphere Composition
	2310G4	Infrared Atmospheric Processes
	2310G6	Local Ionospheric Processes
	2310G7	Atmospheric Dynamic Models
	2310G8	Advanced Weather Satellite Techniques
	2310G9	Global Ionospheric Dynamics
	2311G1	Energetic Particles in Space
	2311G2	Magnetospheric Plasmas and Fields
	2311G3	Solar Environmental Disturbances
62101F	*GEOPHYSICS*	
	4643	Ionospheric Specification
	6670	Atmospheric Science and Technology
	7600	Terrestrial Geophysics
	7601	Magnetospheric Effects on Space Systems
	7659	Aerospace Probe Technology
	7661	Spacecraft Environment Technology
	7670	Optical/IR Properties of the Environment

63410F *SPACE SYSTEMS ENVIRONMENTAL TECHNOLOGY*

2821 Space Systems Design/Test Standards
2822 Interactions Measurement Payload
2823 Charge Control System

63707F *WEATHER SYSTEMS*

2688 Weather Systems (Advanced Development) (Battlefield Weather Systems)
2781 Next Generation Weather Radar

In addition to the continuing Air Force funded projects cited above, AFGL participates in joint programs supported by the following agencies:

1) U.S. Air Force
   - Space Division
   - Ballistic Missile Office
   - Air Force Weapons Laboratory
   - Air Weather Service
   - Electronic Systems Division
2) Defense Advanced Research Projects Agency
3) Defense Communications Agency
4) Defense Mapping Agency
5) Defense Nuclear Agency
6) Department of Energy
7) National Aeronautics and Space Administration
8) Navy

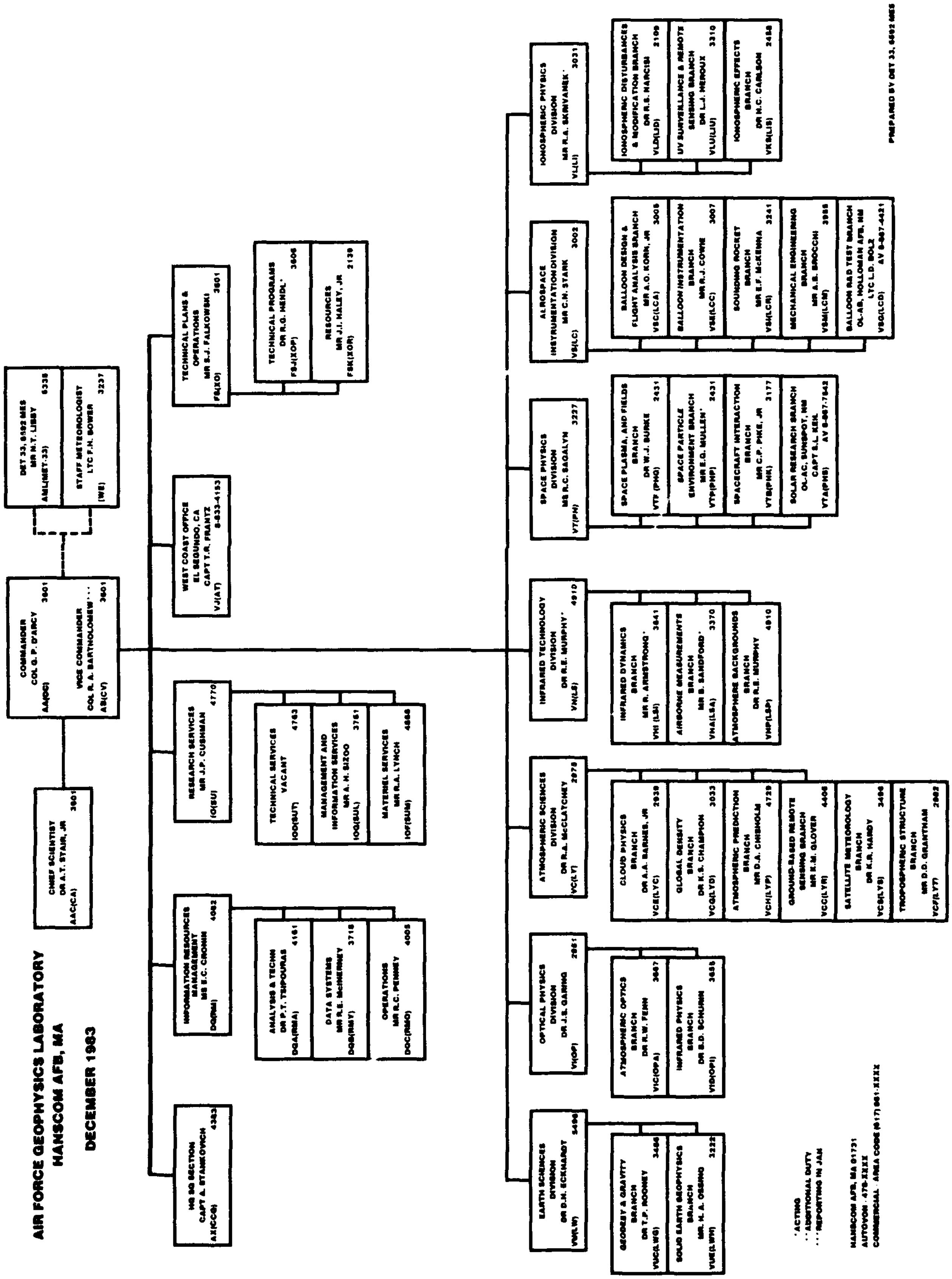
Appendix B

AFGL ROCKET PROGRAM: January – December 1983

Date	Launch Site	Vehicle	Experiment	Scientist	Results
1 Mar 83	WSMR	Astrobee F	SES	McKenna	Success
18 Mar 83	PFRR	Talos-Castor	ELIAS	Nadile	Success
12 Apr 83	PFRR	Sergeant	FWI	Cook	Success
19 Apr 83	WSMR	Aerobee 170	UV	Heroux	Success
14 Jun 83	PFRR	Super Arcas	STATE	Philbrick	Success
15 Jun 83	PFRR	Nike-Hydac	STATE	Philbrick	Success
15 Jun 83	PFRR	Super Arcas	STATE	Philbrick	Success
17 Jun 83	PFRR	Super Arcas	STATE	Philbrick	Success
24 Oct 83	WSMR	ARIES	ELC-1	Price	Success
31 Oct 83	WFS	SONDA III	IMS	Narcisi	No Chance
9 Nov 83	WFS	Nike-Tomahawk	IMS	Narcisi	Success
14 Nov 83	WFS	SONDA III	IMS	Narcisi	No Chance

WSMR —White Sands Missile Range, New Mexico
PFRR —Poker Flat Rocket Range, Alaska
WFS —Wallops Flight Station, Virginia

APPENDIX C


AIR FORCE GEOPHYSICS LABORATORY
HANSCOM AFB, MA
DECEMBER 1983
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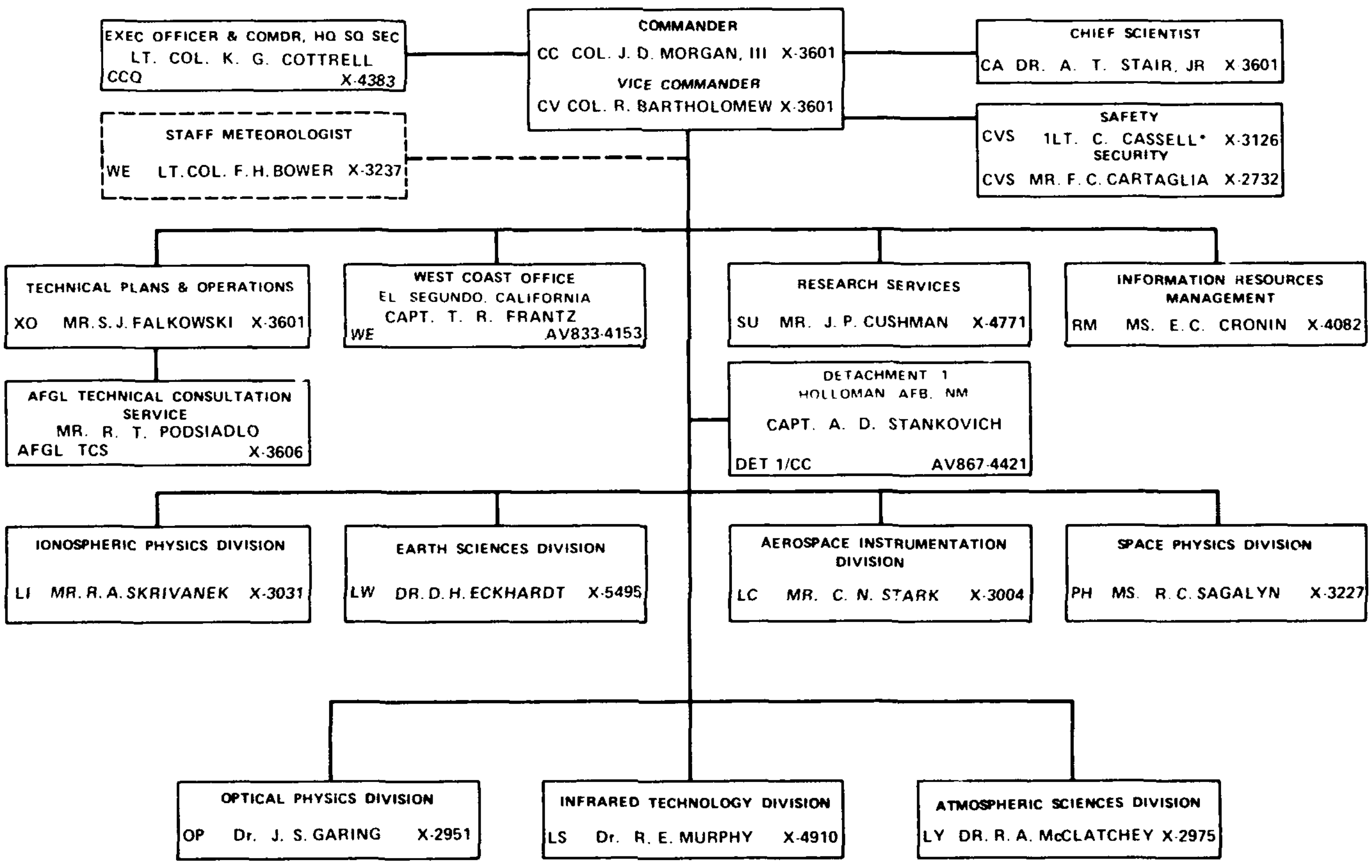

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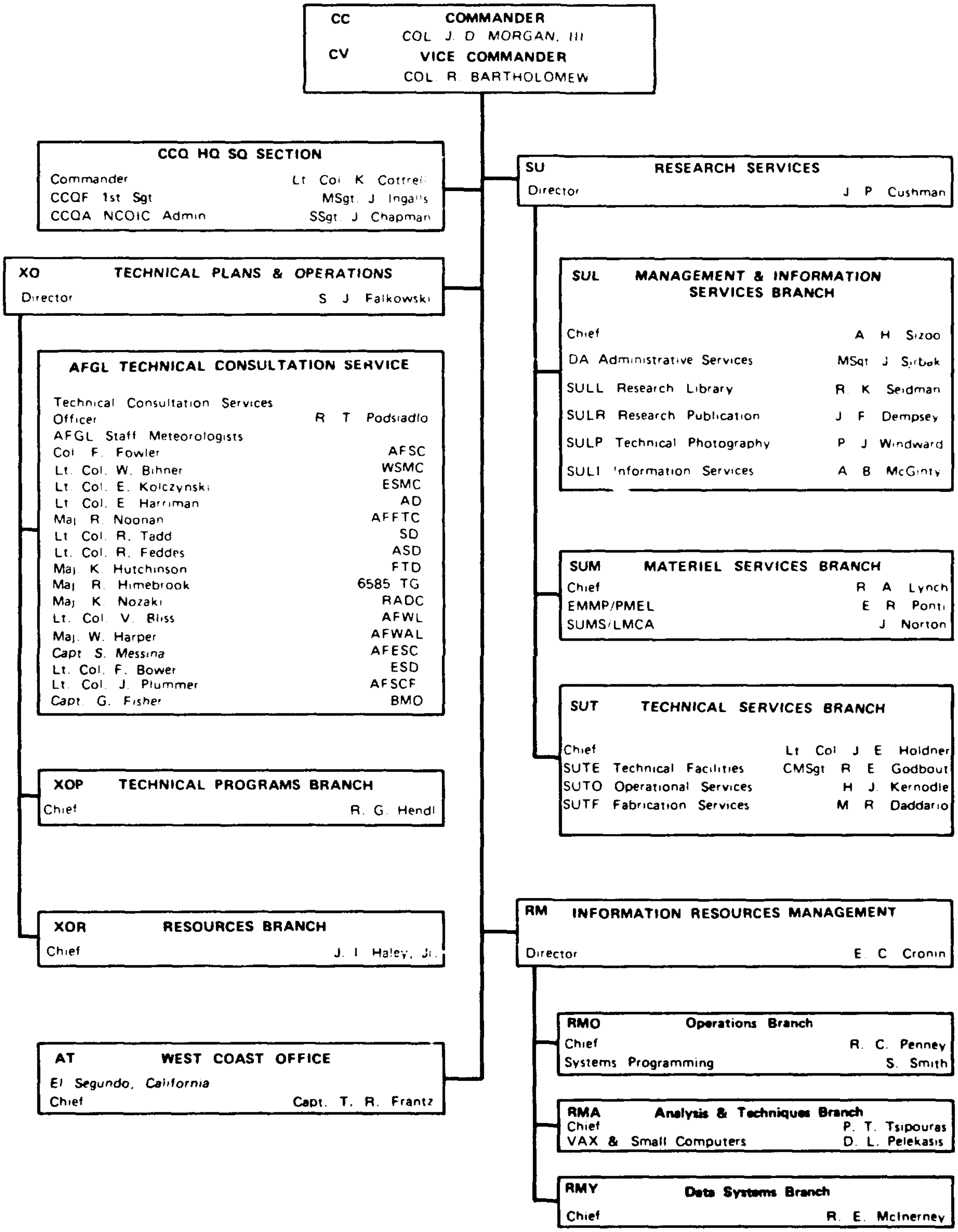

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